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EFFECTS BASED OPERATIONS (EDO) ENDSTATE

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STINFO FINAL REPORT

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13. ABSTRACT *(Maximum 200 Words)* The subject effort is part of the AFRL Effects-Based Operations Program. The goal of this effort was the development of technology for modeling operational-level adversary target systems and centers of gravity (COG). This effort specifically focused on the cross-target systems analysis to predict direct and indirect effects. An analysis of the combination of physical (e.g. petroleum, electric power) and behavioral (e.g. leadership) COGs at the operational level models was performed and the results were incorporated in the EndState Tool. The approach employs model abstraction techniques, the development of effects indicators, and the ability to compute limited enemy workarounds. The EndState Tool combined with the AFRL Strategy Development Tool provides an effects based capability for planning, targeting and assessmen.			
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1 INTRODUCTION

1.1 EBO EndState Objectives

Any effects-based operations (EBO) approach to plan, execute, and assess air operations must account for the fact that opponents are intelligent, devious, and proactive. The effects of a candidate operation cannot be determined by a linear cause-and-effect analysis (e.g., bombing a bridge causes a convoy to stop, which prevents fuel from reaching armored forces) that link a target to some desired effects. Why? Because the opponent can react (e.g., reroute the convoy over another bridge, or draw fuel from another depot), anticipate (e.g., covertly stockpile fuel near the area of operations, before the war begins), and otherwise *work around* our desired effects. Effects do not occur because we desire them; effects occur because we leave the opponent no option other than to permit them.

Because opponents can intervene between targets and effects, we must anticipate their actions. This is a key element of military analysis, and raises both methodological and technical challenges. Methodologically, we can anticipate their actions on the basis of:

Capabilities - what they could do, given the resources remaining at their disposal;

Rationality - what they should do, if they were to intelligently pursue their objectives;

Intentions - what they would do, given past practices, habits, and procedures;

and get different effects predictions in each case. Which one is right? The correct answer is "we cannot be sure". History is full of examples of irrational action, concealed intentions, and underutilized capabilities. However, we can anticipate the *range* of opponents' actions, factor them into our effects-based analyses, and apply sensors to determine which of the potential actions actually unfold.

Anticipating enemy workarounds requires an understanding of the enemy's *Centers of Gravity* (COGs). Centers of Gravity are those characteristics, capabilities, or localities from which an enemy derives its freedom of action (to work around our interventions), its physical strength or its will to fight. Opponents' COGs take many forms, from highly regularized engineering structures (military logistics, infrastructure

systems) to amorphous social structures (political support, leadership relations). Likewise, the models and technology required to predict opponents' actions take many forms, ranging from analytic solutions of games over networks to subjective analyses of social linkages.

The goal of EBO EndState is to develop and demonstrate technology to identify targets that will generate desired effects and further to assess the level of the effects brought about by a targeting action. To perform these tasks the EBO Endstate requires access to detailed information on enemy facilities (location, function, capacity, etc.) and linkages between these facilities (supply rate, commodity, etc.). This Order-of-Battle information is typically stored in the Modernized Integrated Database (MIDB). As a result, a critical feature of EBO EndState involved developing an interface to absorb and understand information from MIDB databases. In addition to Enemy Order-of-Battle information, EndState functionality requires access to Effects based plans and COG models. To facilitate these requirements, ALPHATECH (with AFRL's encouragement) decided to implement EBO EndState as a component of AFRL's Strategy Development Tool (SDT). This provides EBO EndState with access to both SDT's plan authoring information as well as models developed under SDT's COG Articulator component. The complete integration of these components provides an end-to-end set of tools for effects based planning, targeting and assessment. Further, this modular design allows EBO EndState to export targeting selections directly into the effects-based plan at the appropriate point in the plan hierarchy.

1.2 EBO EndState Capabilities Summary

EBO EndState capabilities incorporated into the SDT product include both automated and manual targeting and target system analysis functions. The EndState Target Query Tool provides a graphic interface to identify targets by Type, Location, Links (to other targets), Name or Target System. Results from these queries are provided in tabular form as well as map based displays. Once identified, target can be selected as direct or indirect targets and exported to Strategy Development Tool (SDT) based plans. In addition to specifying targets for prosecution, targets can be designated with exclusion constraints (Do Not Strike or Do Not Effect) and similarly exported to SDT. EndState functionality examines all prosecuted targets to insure compliance of these exclusion

constraints (warnings are provided for constraint violations). EndState's Option Generation capabilities use node and link (when available) attributes to propose targets that achieve desired effects as defined in an SDT based plan. Finally, EndState's Target Systems Analysis (TSA) capability provides a qualitative estimate of the effects of a plan on interrelated networks. These estimates are provided to the warfighter as graphs of production and consumption capabilities over time, again this information is fully integrated with the SDT plan authoring system and the map based display. Further details of these capabilities and the technology behind their development are provided in subsequent sections.

1.3 Document Organization

This final report for the EBO EndState program is organized as follows:

- Section 2 provides technical accomplishments of EBO EndState development performed for AFRL
- Section 3 presents software requirements for the AFRL EBO EndState software development
- Section 4 presents the AFRL EBO EndState System Specification
- Section 5 provides software design for the AFRL EndState implementation
- Section 6 provides highlights and lessons learned from JEFX 04
- Section 7 Provides a summary of work accomplished for the DARPA EndState effort
- Appendixes A-F provide background material and references

2 AFRL ENDSTATE TECHNICAL ACCOMPLISHMENTS

2.1 Target System Analysis (TSA)

EBO Endstate has implemented a framework for cross-network target system analysis. This framework allows the integration of simulation models that work on different timescales or even different level of data aggregation. It is based on a micro-economic model developed by a consultant [Dahleh]. The framework integrates models that do not need to be aware of each other, to simulate the effects of network damage as the effects propagate through the networks without requiring a tight coupling between the models.

The interface is done through a simple XML-based protocol, which allows models to be added and removed with ease. Early in the contract, we developed complicated, physics-based models for the initial use, which ran as external programs. Later in the contract, these models were replaced with models based on the data available from the MIDB. No modifications to the central algorithm were required for this change.

When provided with a plan, a list of direct and indirect targets, and no-strike and no-effect lists, the TSA module provides a description of the effects that targeting the direct targets will have on the indirect target. For each target (direct or indirect) as well as nodes on the no-strike and no-effect list, the module generates a time profile indicating the level of activity at the node.

Central to the module is a micro-economic algorithm. A set of prices is created for all commodities. These prices are internal to the model and not visible to the user. Real-world price data is not required. The price of each commodity is location dependent and piecewise constant in time. Each model is given these prices and then performs an internal optimization of how to best control its network with the current prices. The values and locations of externally demanded commodities are provided to a central coordinator, along with data about the location of commodities supplied for other networks. The central coordinator then examines the balance of supply and demand at each location and in each time interval. If supply exceeds demand at a given location, the price is lowered based on the amount of the excess and the duration in time. Likewise, if the demand exceeds the supply, the price is raised.

The algorithm understands the concept of inventory. If supply shortfall is less than the current inventory, the prices are not adjusted but the inventory level is lowered. Similarly, an excess of supply does not modify the prices if there is sufficient inventory capacity to hold the excess commodities.

After all of the prices are modified, they are returned to the models and the process is repeated until supply and demand have converged. An adaptive algorithm controls the size of the change in price to speed convergence and prevent repeated oscillations in the prices.

The breakpoints in the price values are dynamically generated. They naturally occur at times when targets are struck, but they can also be generated through an imbalance in supply and demand combined with a limited inventory. If the inventory is exhausted (or filled), the price will rise (or fall) immediately afterwards, representing that the demand is no longer being met.

Several types of models were developed to support the TSA analysis. The most straightforward are the infrastructure models. These are based on the physical infrastructure. They use a linear program to model the flow within a single network. Piecewise linear costs are used in the objective function to provide stability when the costs change and to achieve a realistic allocation when nodes are consuming at less than full capacity.

The second type of model is an end-user model. Civilian and military users consume the commodities, but do not produce anything that is covered within the TSA analysis. To handle this, a "constant demand" model was developed. The model normally returns a constant value for the demand, unless the price for the commodity rises above a threshold. In that case, the demand begins to decrease slowly, until it eventually reaches zero.

The last model was the leadership model. The market-based economics algorithm that is central to the TSA module will reach the most "efficient" solution, as would be expected in a country with a free market. The countries against which we typically would apply TSA are generally autocratic countries with a state directed economy. As such, even if it is more efficient to spread a shortage over everyone, the leadership is likely to insist (for example) that the military receive full supplies, even if civilians receive very little or nothing. To model this, we created a Bayes net to model the probability of the leadership achieving its goals based on (among other factors) the supply of various commodities to different sectors. When a particular sector is being shorted, it increases the demand of an aggregate commodity representing the supply to that sector. This behaves similarly to a subsidy for that sector, so that supply will increase. The model performs an optimization, balancing the probability of achieving its objectives against the cost of the subsidies. In our models, this typically results in

the military receiving full supply whenever the network actually supports such a situation.

2.2 Option Generation (OG)

EBO Endstate has implemented a framework for generating targeting options. The framework reads facility data from the MIDB in addition to using plan data from SDT. If the MIDB contains link data, that data is also used, but link data is optional. The Option Generator requires a list of indirect targets from SDT as well as a no-strike list and a no-effect list. It applies several algorithms depending on the data available in the MIDB and information from the plan.

Common components

Regardless of the data available, the framework begins with some common steps. It searches the plan for effects with indirect targets. It then looks at the leaf effect or task of those effects, and determines whether we are seeking to affect production of resources, transportation of resources or both. (In all cases where it is unable to determine intent from the plan, it assumes all possible options are desired.) It also looks at the leaf element to determine which network (e.g., EP or POL) the user desires to affect. It then queries the MIDB to find all possible targets that match these requirements and excludes those that are on the no-strike list or the no-effect list. The framework then evaluates each possible target using the algorithms described below. Any target selected by at least one algorithm is sent to the Map Tool as a proposed target, where the user can view the target on the map and see which parts of the plan the target supports. If the user agrees with the option generator, the target can be added to the plan.

Node based algorithms

If only node data is available, the Option Generator uses two algorithms. The first algorithm is used if the plan indicates that targeting of production facilities is desired. If the plan indicates that targeting of transportation facilities is desired, then the second algorithm is used. If the plan is ambiguous, then both algorithms are used and the results are combined.

In both algorithms, the affected targets are grouped into clusters. This allows several small but nearby targets to be treated as a single larger target, which can improve the performance of the algorithms. For example, consider 10 targets that each consumes one unit are close to 5 facilities that each produces 2 units. If the affected targets are considered separately, the algorithm might select one of the production facilities when each affected target is considered and then terminate, since the production capacity is notably larger than the consumption capacity. By grouping the affected targets, the consumption capacity is increased and the algorithm will select more of the production facilities.

The first algorithm is used when the plan indicates that we desire to target production facilities. The basic concept is to locate targets that are likely to supply the affected target. Each group of affected targets is considered in turn, and proposed targets are generated for the group. All of the proposed targets are combined into a single set at the end of the algorithm. The algorithm assigns a score to each possible target based on the capacity of the target and the distance from the indirect targets. Larger capacities and shorter distances give higher scores. It then sets a threshold based on the typical score of possible targets near indirect targets. Any possible target whose score exceeds the threshold is included in the generated target list.

The second algorithm is based on the observation that to suppress the flow of commodities, targets need to be selected from all possible directions of approach. Otherwise, the flow from an uncovered direction will increase to compensate for the decrease from the other directions. The algorithm must also be able to handle the case where there are no targets in a given direction, such as when the affected target is on the coast. This algorithm adopts concepts from Coulomb's law in electrostatic physics. As with the first algorithm, each group of affected targets is considered and the proposed targets from each group are combined to form the final list of proposed targets. Each indirect target is assigned a positive charge and each possible target is assigned a negative charge, with the charges being proportional to the capacity. The possible target with the largest attractive force towards the affected target is selected. The force calculations are redone, but the repulsive force of the selected targets is also included. This encourages the selection of targets that are one the opposite side of the indirect target, as the

previously selected proposed target “screens” the affected target. The process repeats until no possible target has an attractive force.

Link Based Algorithms

When link data is also available, the Option Generator uses three algorithms. One algorithm is used when the plan indicates that production facilities are to be targeted, while the other two are always used. The resulting target lists are merged.

With these algorithms, the affected targets are not grouped together. Instead, the algorithms consider all of the affected targets at once, so that a global analysis is performed. Groups of smaller affected targets are not neglected in favor of less numerous but larger affected targets, as the global analysis will recognize the effect on several smaller targets in the same manner as an effect on a single target with the same aggregate capacity.

The first algorithm is based on a shortest path algorithm. The concept here is that nearby producers are the likely suppliers, so targeting them will be helpful. It begins by creating a graph representing the network structure. The graph includes cross-network arcs, so the proposed targets may be in any network that can supply (directly or indirectly) the indirect targets. It then applies a shortest path algorithm to find the geographically nearest producers. It adds these facilities to the proposed target list, until the sum of their capacity exceeds the capacity of the indirect target multiplied by a scale factor.

The second algorithm is based on disrupting transportation, so that flow from the producers to the consumers is not possible. This creates the possibility of finding a small set of possibly distant targets that still achieve the desired effect. It also starts by creating a graph of the network. It applies a modification of the maximum flow-minimum cut (MFMC) algorithm to find the minimal set of nodes that will separate the network, so that no indirect target is connected to any producer. The facilities corresponding to the minimal set is returned as the proposed target list. Several modifications of the basic MFMC algorithm were needed for this. The standard MFMC algorithm assumes that any link can be selected, while we only want to select links that have a possible target on them. To handle this, we increase the capacity of links that are not connected to targets

so that they will not be selected. We also want a set of facilities, not a set of links. This is done as a post processing step. Once the links are selected, we solve an assignment problem, minimizing the total capacity of the selected targets.

The third algorithm attempts to locate the facilities that will have the greatest effect. It generates a linear program (LP) to simulate the flows through the networks and the transformation of one commodity into another at plants. It then solves the LP by maximizing consumption at the indirect targets. The dual values of the solution are examined to determine which nodes in the network would have the largest effect, using the dual value multiplied by the capacity as an estimate of the effect. The LP is modified to represent the effect of targeting those nodes, and the LP is resolved. This process is iterated until the consumption at the indirect targets drops to the value indicated in the SDT plan.

2.3 Visualization (Target Set Tool (TST) and Query Tool (QT))

EBO Endstate has implemented a visualization tool for examining and querying physical networks. The tool is built on top of BBN's OpenMap tool (http://openmap.bbn.com). It provides several functions: display of physical networks, manual targeting, query functions and display of DTED data. It also provides graphical display of results from Target Systems Analysis and Option Generation as described in the preceding sections.

The tool displays node and (when available) link data, overlaid on top of a political background. Nodes can display the name of the node, and access to more detailed information is available through use of the mouse.

The user can manually select nodes and flag them as either direct or indirect targets. These nodes can than be exported to SDT and added to the plan. The capture (Figure 1) below depicts this capability as viewed in SDT [Pioch].

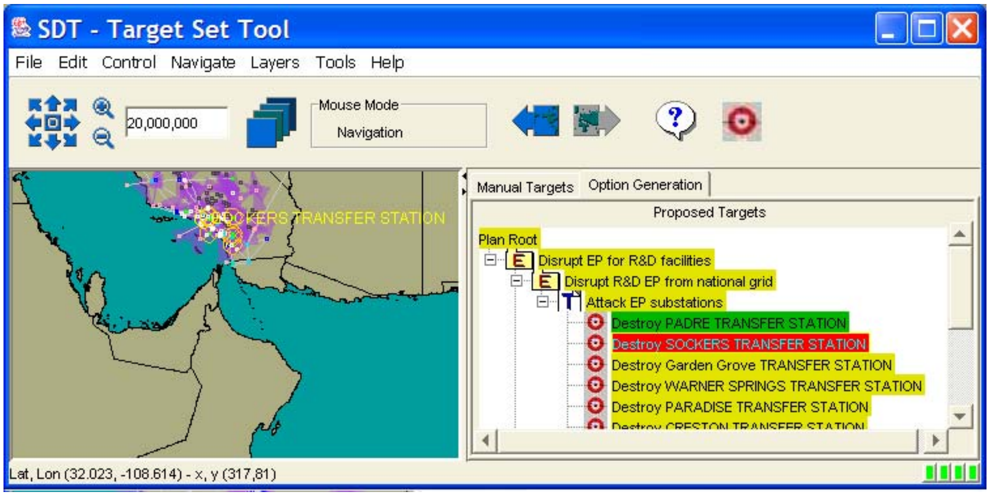


Figure 1 – EndState Target Set Tool (SDT Capture)

Nodes can also be color coded according to type as selected by the user. The configurable legend shown below depicts how specific node types can be color coded for easy identification on the map display (see Figure 2).

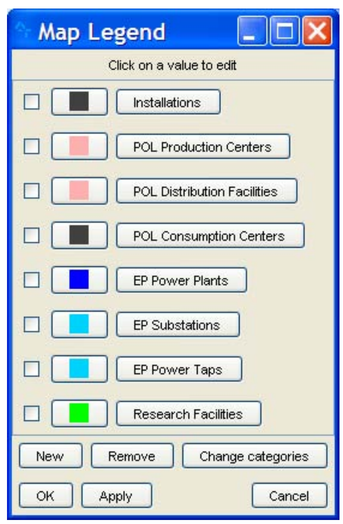


Figure 2 — EndState Map Legend

Endstate visualization capabilities include a Query Tool that allows the user to search for nodes according to specific criteria. The user can search for nodes by name, BE number, category code, distance from other nodes, or by target system. The results can be selected for display on the map and flagged as direct or indirect targets (graphic below – Figure 3).

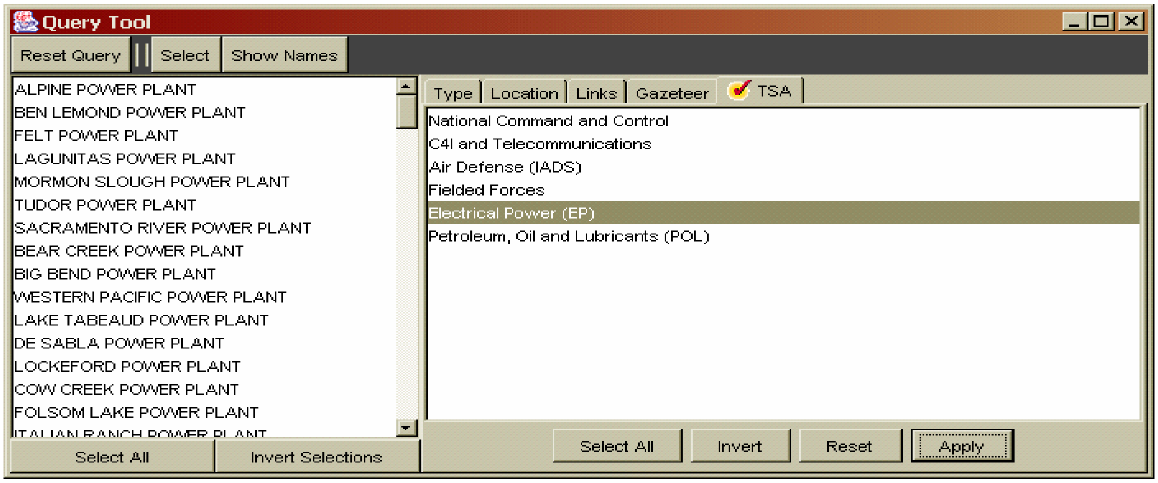


Figure 3 — EndState Query Tool

There is also an interface for displaying the results of Option Generation. This allows the user to approve the results of the algorithms and add them to the plan (see Figure 4 below). In this graphic, we see a number of nodes (facilities from the MIDB) selected by the Option Generation capability as potential targets which support a given task to satisfy a particular effect defined in the plan. These potential targets are presented along with the entry point (task node) in the plan where they have been identified. The user may select a set of these potential targets (highlighted in green) for direct export to the plan. This export of targets to the plans is executed by selecting the “bullseye” button in the Target Set Tool once targets have been highlighted.

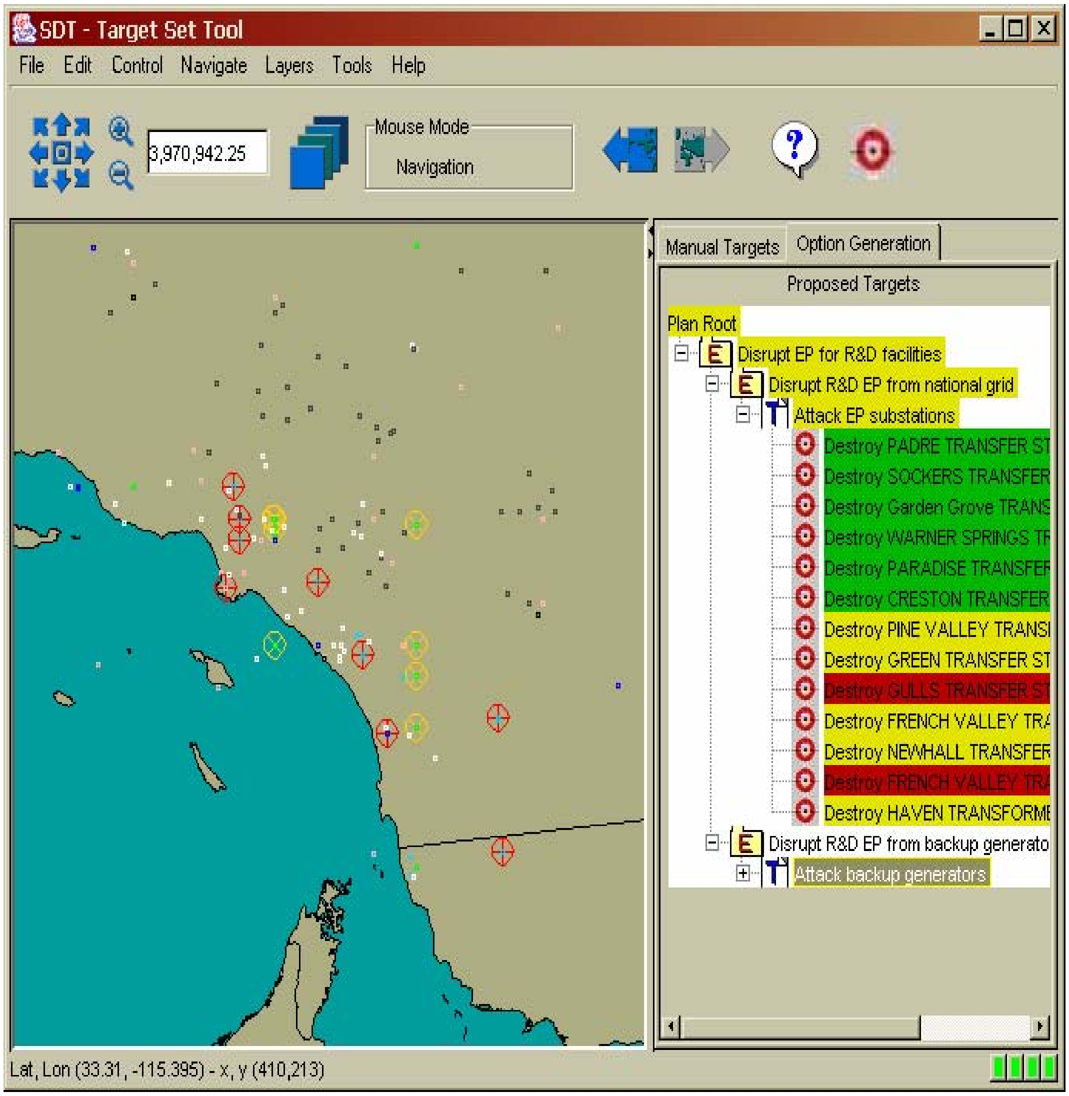


Figure 4 — EndState Option Generation Results Display

In addition to Option Generation results, Endstate visualization capabilities depict the results of Target Systems Analysis over time. The captures below (Figure 5) show estimated operational capability of nodes (as indicated by bars associated with the node) at two distinct points in time. The Target Systems Analysis (as described above) propagates the impact of targeting actions over time. Hence, we see a degradation in node performance as the effects of those targeting actions propagate through the system.

Figure 5 — EndState Target Systems Analysis Results Display

Finally, EBO EndState has implemented methods to specify targets as "Do Not Strike" or "Do Not Effect" targets. This capability stores such designations with target information and analyzes each targeting decision based on these conditions. Attempting to strike a target designated as "Do Not Strike" or attempting to effect targets designated as "Do Not Effect" will result in an error (Figure 6).

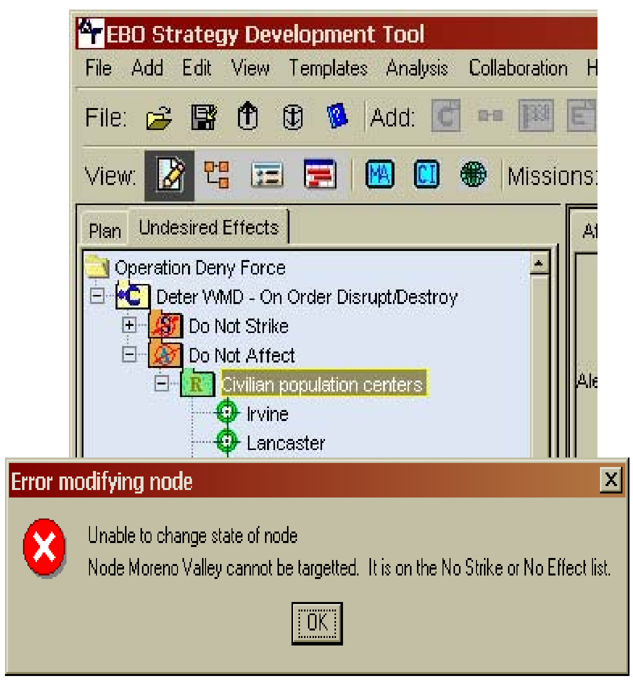


Figure 6 — Unintended Effects Display

3 AFRL ENDSTATE SOFTWARE REQUIREMENTS

3.1 System/Subsystem Specification

The purpose of EndState software is to receive a plan from SDT and send a prediction of that plan's outcome back to the SDT. The predicted outcome will be based upon simulations in a number of models known as COGs. Endstate software should be flexible enough to allow for additions of new COGs. Each COG will model a specific aspect of the plan such as Electric Power or the road networks. Endstate software must fulfill the following requirements:

1. Communicate with SDT
2. Mechanism for communication between Endstate components
3. Communicate with COGs
4. Coordinate communication between COGs
5. Coordinate time between COGs during simulation
6. Produce a prediction about the SDT plan's outcome
7. Provide a graphical map tool
8. Allow queries of facilities in the map tool
9. Generate targeting options
10. Report on undesired effects
11. Allow the user to specify facilities that should not be affected or targeted
12. Produce a report of the effects at facilities that should not be affected
13. Support queries related to the target system templates developed for JEFX 04

Endstate Software will be written as much in Java 1.4 as possible but only guaranteed to run on windows NT. There will be 5 main components; the Coordinator, Predictor, Temporalizer, Target SetTool, and Option Generator. Only the Target Set Tool will have a GUI interface viewable by the user. Software from the SDT or COGs may communicate with Endstate via XML messages sent over sockets to the Coordinator. A user or SDT software may start the Endstate software via a software call or the user choosing the exit button on the Coordinator may close it.

Coordinator

The Coordinator will act as an intelligent server. It will accept inputs of XML messages and output XML messages to the appropriate software component using a

publish/subscribe method. Software components that communicate with the Coordinator are the Predictor, Temporalizer, Option Generator, Target Set Tool and the SDT Software. The Coordinator will also know about all of the COGs as they are added as well as how to coordinate communication with each COG. There will be a GUI with a window displaying the current communication messages as well as an exit button to close Endstate software. This window will only be visible when the software is configured for development.

The predictor takes as inputs, via messages from the Coordinator, the desired actions from the SDT, the target sets from the SDT, and predictions from the COGs. The predictions from the COGs at each time step during each COG's simulation are matched to the desired actions and targets to create graphs charting the predicted probability of each target and action over time. The resulting graphs are sent to the Coordinator and received by the SDT.

The Temporalizer's function is to coordinate simulation time information between COGs. The Temporalizer receives as inputs a list of COGs that are used in Endstate to obtain predictions about a plan and coordinates time between those COGs as they simulate. After all COGs have finished their simulations, the Temporalizer sends a message to alert that all simulations are complete.

The SDT provides the target set for simulations. The user inputs targets via a GUI and targets are sent to COGs as well as the Predictor for initializing simulations. The targets set by the SDT are targets that will be used to facilitate the plan obtained from the SDT.

Option Generation

This section covers item 7 above.

The Option Generator (OG) will work with data available from the SDT plan and from the secret level MIDB. As such, the OG will work with the SDT *in theater*. The OG will perform several tasks:

1. Query the MIDB for data on facilities and their attributes
2. Employ heuristic algorithms to generate candidate target sets
3. Automatically generate target sets from the Effects-Based Plan

4. Include visualizations using the Target Set Tool

5. Allow updates from intelligence and BDA to refine target sets

6. Be fully integrated with the SDT and existing Endstate components

The following subsections provide details of these requirements.

Query MIDB

The OG will interface with the MIDB using SQL queries. This will provide information about nodes but not about links. The initial MIDB will be the unclassified MIDB mockup provided by Air Force Research Laboratory - Rome. That database must have the same schema as the current secret MIDB. They fields should also be populated in the same manner as the secret MIDB. If these requirements are met, transitioning to using the real MIDB should be simple and straightforward.

Heuristic algorithms

The heuristic algorithms used by the OG will generate a target set based on the information in the SDT plan, the node information in the MIDB and BDA/intelligence data in the MIDB. Details of the algorithms will be determined during the analysis/design phase. It is likely that several iterations will be required to finalize the algorithms.

Generate target sets

The OG will run the heuristic algorithms to generate a target set. During this phase, the output will be deterministic. Given an SDT plan, an MIDB database and a specific set of BDA reports, the OG will generate exactly one target set. If queried again, it will generate the same target set.

The OG will subscribe to *plan* messages from the XML server. Upon receiving a *plan* message containing affected targets, it will respond with a *proposedTargetSet* message. The format of the *proposedTargetSet* message will contain elements similar to those in the *targetSet* and *augmentation* messages. The portions similar to the *targetSet* message will provide a list of the proposed targets. The parts similar to the

augmentation message will provide a skeleton plan fragment, to link the targets with the lowest level nodes in the existing plan. The details will be finalized during the design process.

Visualization

The current Target Set Tool (TST) will be extended to show the generated target set. It will subscribe to the *proposedTargetSet* message and update its display when the message is received.

The Strategy Development Tool (SDT) must add the appropriate nodes to the plan when the user approves the proposed target set.

Refining target sets

If the intelligence or BDA information in the MIDB is changed, the OG may generate a different target set. This will be a manual process, requiring the user to request an updated target set.

Integration with the SDT and existing Endstate components

The OG will be fully integrated with the SDT and the TST. It is philosophically inconsistent with the Cross Model Coordinator (XMC) framework. No effort will be made to integrate the OG and the XMC or to avoid conflicts if both are used simultaneously.

Networks

The Phase I option generator for facilities will support the following networks:

Electric Power

Telecommunications

Petroleum, Oil and Lubricants and Natural Gas

Rail and Road LOC

Do Not Effect Facilities

This section covers items 10, 11, and 12.

The intent of this enhancement is to allow the user of SDT to flag facilities that should not be directly targeted (Do Not Target (DNT)) or indirectly affected (Do Not Effect (DNE)). The user will receive feedback if attempts to violate these constraints occur.

The following requirements must be met.

1. The user must be able to select an individual facility as a DNE or DNT.
2. The user must be able to select a group of facilities by category code as DNE or DNT.
3. If the user attempts to select a facility on the DNT list as a direct target, he will be notified and prevented from doing so.
4. If the user attempts to select a facility on the DNE list as a direct or an indirect target, he will be notified and prevented from doing so.
5. Outage profiles will be provided for DNE targets. These will be similar to what is currently provided for indirect and direct targets. This will only happen if the effect node contains a description that Endstate understands, similar to the current restriction on indirect target and outage profiles.
6. If an outage profile is provided, and the facility is affected beyond the limits stated in the effect, the user will be notified.
7. Both the DNE and DNT lists will be global. A future version may provide DNE/DNT lists that are limited to a specific phase, effect, etc.

TSA Queries

This section covers item 13 above.

The C2TIG has identified seven target systems that are to be involved in the JEFX exercise. These systems are as follows:

1. National Command and Control
2. C4I and Telecommunications
3. Air Defense (IADS)

4. Fielded Forces
5. Electrical Power
6. POL

To support work in with these systems, the software will allow the user to specify a target system and restrict the Query Tool selection to just facilities that belong to that system.

Requirements

The following requirements will implement this task.

1. The user must be able to select facilities for each target system. This requires an additional panel in the Query Tool.
2. The software must convert the target system into a collection of category codes, according to the table below. In the category codes, x is used where any digit is acceptable. Category code definitions can be found in Ref. MIDB.

Target System	**Category Codes**
National Command and Control	41xxx, 527xx, 741xx, 7741x, 759xx, 773xx, 775xx, 82xxx, 874xx, 89xxx, 91xxx, 93xxx, 941xx, 96xxx
C4I and Telecommunications	41xxx, 74xxx, 774xx, 82xxx, 83xxx, 899xx, 93xxx, 94xxx, 96xxx, 981xx
Air Defense (IADS)	80xxx, 81xxx, 82xxx, 85xxx, 86xxx, 872xx, 873xx, 877xx, 879x4, 879x5, 882xx , 89003, 983xx
Fielded Forces	63xxx, 642xx, 646xx, 649xx, 662xx, 663xx, 664xx, 666xx, 668xx, 669xx, 691xx, 67xxx, 752xx, 76101, 7631x, 7813x, 7814x, 80xxx, 81xxx, 84xxx, 85xxx, 86xxx, 87xxx, 88xxx, 89xxx, 90xxx, 91xxx, 92xxx, 941xxx, 95xxx, 96xxx, 97xxx, 98xxx
Electrical Power (EP)	32xxx, 42xxx
Petroleum, Oil and Lubricants (POL)	14xxx, 15xxx, 210xx, 211xx, 212xx, 213xx, 214xx, 215xx, 217xx, 218xx, 372xx, 4072x

The category codes for EP and POL are taken from the MIDB SOP.

Command, Control, Computers and Intelligence (C4I)

The category codes for C4I and Telecommunications are based on the Califon Command, Control, Communications, Computers, and Intelligence (C4I) Target System Analysis. It does not give explicit category codes, but instead provides guidelines for requested data. From these requests, we extrapolated the following category codes. The software will not subdivide the system according to the bullets below, so the exact association of category codes with the individual items is not important.

Governmental facilities – 74xxx, 774xx, 93xxx, 94xxx

Telecommunication links and nodes – 41xxx

TV, radio, wireless phone, SATCOM

Broadcast stations, repeater stations, microwave towers

Network hubs, fiber optics and coaxial cable

Computer network facilities

Facilities with Information Operations or PSYOP capability – 83xxx

National intelligence facilities – 899xx

SIGINT or HF/DF sites

SATCOM intercept, ELINT and intelligence related communications

Intelligence HQ

Air Operation Centers (ADOC, ZOC, IOC, RCC) – 82xxx

Army Corps and Naval Flotilla and Costal Defense HQ - 96xxx, 981xx

Special Operation Forces facilities

Fielded Forces

The category codes for Fielded Forces are based on the Califon Fielded Forces Target System Analysis (Ref. TSA-AFRL). It does not give explicit category codes, but instead provides guidelines for requested data. From these requests, we extrapolated the following category codes. Category codes pertaining to production of military supplies have been excluded, but facilities for repair/rebuild have been included. The software will not subdivide the system according to the bullets below, so the exact association of category codes with the individual items is not important.

Corps HQ, garrisons, depots, FOL – 63xxx, 642xx, 646xx, 649xx, 662xx, 663xx, 664xx, 666xx, 668xx, 669xx, 691xx, 752xx, 76101, 7631x, 7813x, 7814x, 89xxx, 90xxx, 91xxx, 92xxx, 941xxx

Division HQ

Brigade HQ

Flotilla HQ – 67xxx, 95xxx, 96xxx, 97xxx, 98xxx

Air force, bases, airfields – 80xxx, 81xxx, 84xxx, 85xxx, 86xxx, 87xxx, 88xxx

Special Operations

Strategic Air Defense

The category codes for Air Defense are based on the Califon Strategic Air Defense Target System Analysis (Ref. TSA-AFRL). It does not give explicit category codes, but instead provides guidelines for requested data. From these requests, we extrapolated the following category codes. The software will not subdivide the system according to the bullets below, so the exact association of category codes with the individual items is not important.

Zonal Operation Centers

Regional Control Centers

C3 Battle Management – 82xxx, 81xxx, 89003

SAM facilities – 872xx, 879x4, 879x5

AAA AD units – 873xx, 877xx, 983xx

Forward Operation Locations – 882xx

Repair/Supply Depots – 86xxx

Airfields – 80xxx

EW/GCI C2, Fighter Direction Posts, Reporting Posts

Airborne Early Warning

IADS, IADS/IO and IADS support – 85xxx

National Command and Control (C2)

The category codes for National Command and Control are based on the Califon National Command and Control (C2) Target System Analysis (Ref. TSA-AFRL). It does not give explicit category codes, but instead provides guidelines for requested data. From

these requests, we extrapolated the following category codes. The software will not subdivide the system according to the bullets below, so the exact association of category codes with the individual items is not important.

Governmental facilities – 741xx, 7741x

Military facilities and HQ – 82xxx, 874xx, 91xxx, 941xx, 96xxx

Internal security facilities – 89xxx

Prison/detention facilities – 759xx, 775xx

Police barracks – 773xx

Communication nodes, TV, radio, wireless phone, SATCOM – 41xxx, 93xxx

Broadcast stations, repeater stations, fiber optics and coaxial cable, microwave towers, network hubs – 527xx

4 SYSTEM/SUBSYSTEM DESIGN DESCRIPTION

4.1 System Architectural Design

Figure 7 depicts the basic components of an "End to End" EBO thread. The shaded portions are those developed under the scope of this project. The Plan Editor was developed by the EBO Strategy Development project while the User and Cog Expert nodes represent Human users. Square nodes are used to represent software modules and rounded squares represent files or other methods of data storage/transfer.

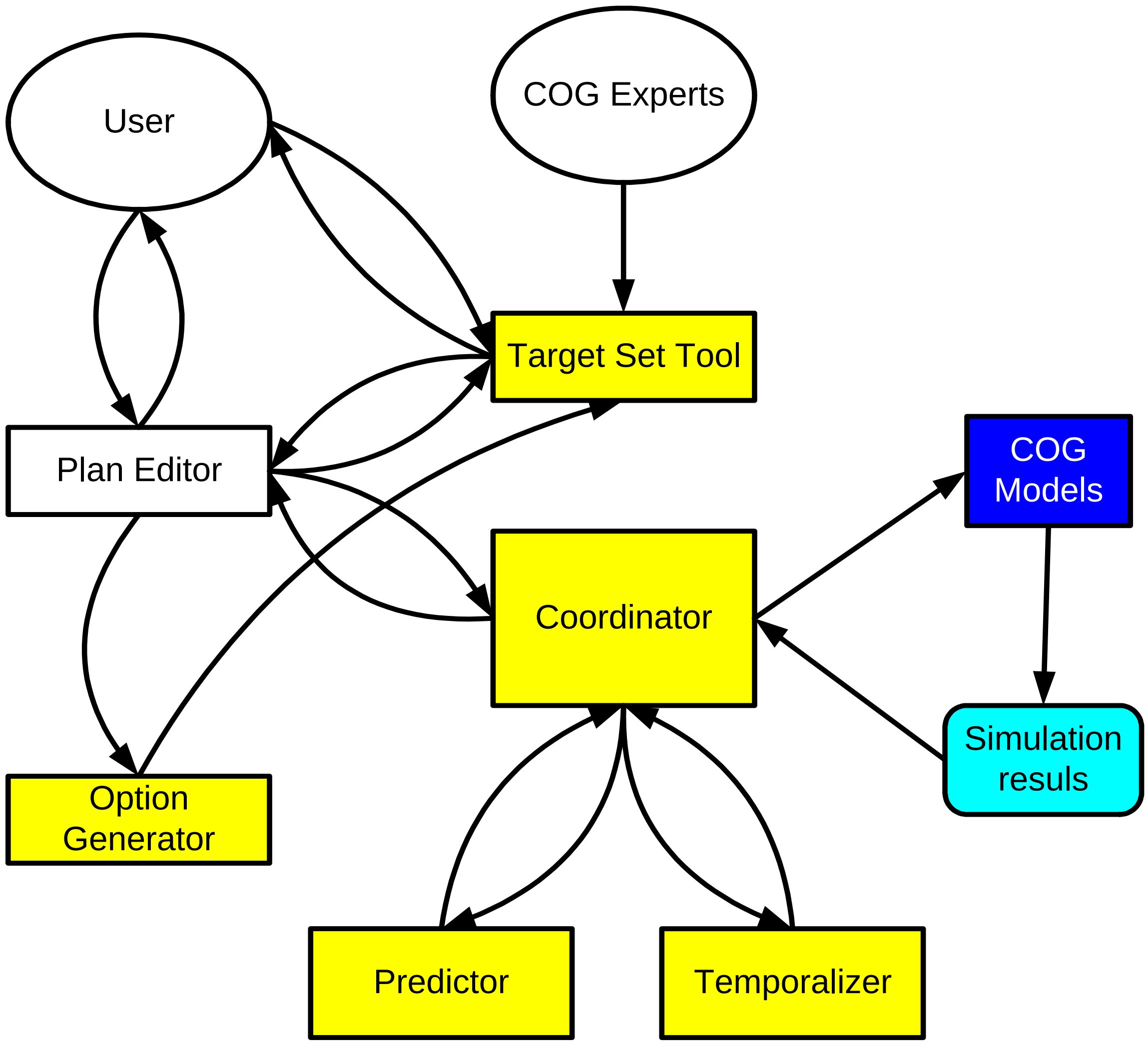


Figure 7 - Components for EBO Interactions.

The Coordinator is the external interface for the EBO Endstate software. It receives information requests from the EBO SDT software. It obtains detailed target sets from the SDT tool. It runs the COG models and translates the output of the COG tools into a common format. Information to the Temporalizer or COGs is forwarded via the

Coordinator. The Predictor will provide the Coordinator with probabilities of achieving the desired effects.

The Coordinator is complex. Figure 8 shows the internal components of the coordinator. It consists of the following components.

- The SDT tool is developed by the EBO SDT team. It sends a plan containing the desired effects and a high level description of the targeting that the plan anticipates. It provides the simulated effects and explanations to the SDT tool.
- The Target Set Interface provides the target sets for the COG tools. It is also part of the SDT tool.
- The Cross-Coordinator produces the simulated results of a target set. It coordinates between the COG models to ensure that the results of the simulations are consistent at the global level. This will be in Java.
- The Single COG Interfaces translate the target sets from the common format used in the other components into the actions that are appropriate for a specific COG. They translate the COG-specific output into a common format. This may be in Java or C++.

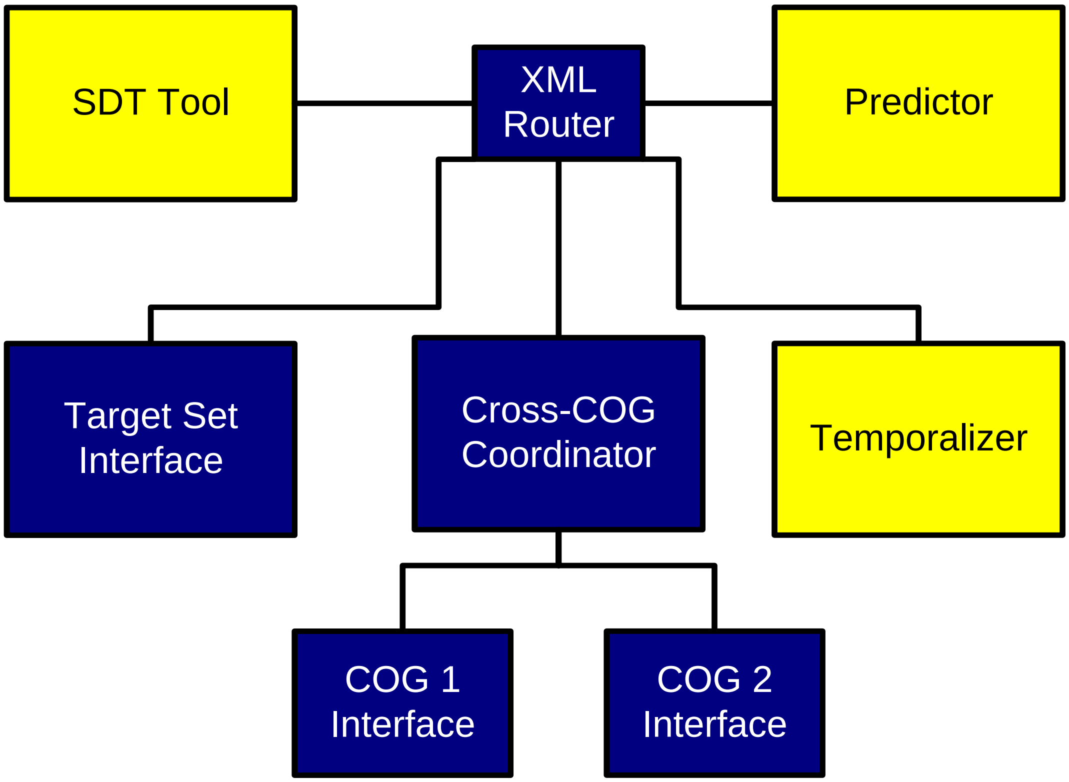


Figure 8 - Coordinator components. External modules are shown in yellow.

The option generator is an independent part of the Endstate software. (Some low level classes will be shared.) It receives requests of proposed target sets from the SDT tool. Based on the data in the request and the type of data available from the MIDB (e.g., does it contain link data), the option generator selects a group of heuristics to propose targets. These proposed targets are sent to the Target Set Tool.

The target set tool displays a map of the region. On the map, direct, indirect, do not affect and do not strike facilities are indicated. After a simulation, the target set tool can also display the results of the simulation. When the option generator is invoked, it displays the proposed target sets and allows the user to export the targets to the SDT plan.

4.2 Requirements Traceability

This section provides a map between the requirement and the components defined in this section.

Requirement	Component
1 Communicate with SDT	Coordinator
2 Mechanism for communication between EndState components	Temporalizer
3 Communicate with COGs	Predictor
4 Communicate communication between COGs	XML Router
5 Coordinate time between COGs during simulation	Cross COG Coordinator
6 Produce a prediction about the SDT plan's outcome	COG Interface
7 Provide a graphical map tool	Target Set Tool
8 Allow queries of facilities in the map tool	Target Set Tool
9 Generate targeting options	Option Generator
10 Report on undesired effects	Predictor
11 Specify facilities to not affect or target	Target Set Tool
12 Produce a report of the undesired effects	Predictor
13 Support queries for JEFX	Target Set Tool

4.3 Software Requirements Specifications

CSCI Requirements

There are five major components: the Coordinator, the Temporalizer, the Predictor, Target Set Tool and the Option Generator. We also specify the components that form the Coordinator.

Coordinator

The Coordinator consists of four components, plus an additional component for each COG. The four components are the SDT interface, the Predictor, the cross-Coordinator and the Temporalizer interface.

SDT Tool

The Plan Editor is being created by the EBO Strategy Development Team (SDT). We therefore must work with the SDT team in determining the best approach for communication between our components and theirs. The following interface specifications must be communicated between EBO EndState and SDT.

1. Coordinator requires desired effects and targeting guidance, which the Plan Editor will provide.
2. The Plan Editor requires the target set, simulated effects and an augmentation for the Bayesian net, which provides detail relating to the current plan. The Coordinator will provide this.
3. File format for data saved by Plan Editor
4. File format for data saved by Coordinator
5. A way for Coordinator to know that the Plan Editor has finished saving data and Coordinator should now run the appropriate model file
6. A way for Plan Editor to know that Coordinator has finished running and it should gather results to show.

Cross-Coordinator

This module runs the side-to-side thread. As input, it receives the target set and the desired effects. It returns an internally consist result from running the COG simulations, including the simulated effects. (Need more detail when S2S thread is better defined.) Additionally, it needs to be aware of what types of desired effects can be addressed by an individual COG.

COG Interface

The COG interface will interact with the COG models, requesting the appropriate data from the model and forwarding it to the XML router.

XML Router

The Coordinator will reuse the XML router from the Active Templates project for routing XML messages.

Target Set Tool

This GUI will be used by a COG expert to enter a detailed target set. It will provide the expert with a summary of the plan to aid in determining the target set.

Temporalizer

This module controls time. It sends messages indicating the current time in the simulation, and receives replies from all components that are interested in time. When it determines that all components have reached an endstate, it sends a simulation done message.

Predictor

This module propagates the results of the simulations in a Bayesian network through time and produces probabilities of achieving desired effects along with mechanisms to explain the effects. It is written in Java. See interface specifications for details.

Option Generator

This module generates targeting options. It receives messages from the SDT containing the plan. It sends messages containing proposed targets for achieving the effects listed in the plan. It uses heuristics to generate those targets. It is written in Java.

5 AFRL ENDSTATE SOFTWARE DESIGN

5.1 SOFTWARE ARCHITECTURE

The software consists of three main components. These are

1. Target Set Tool – provides a map-based GUI
2. Coordinator – performs target system analysis
3. Option Generator – creates sets of proposed targets

Block Diagram

These components interact as shown in the block diagrams of section 3 (refer to Figures 7 and 8).

Components

TARGET SET TOOL

The Target Set Tool is the GUI for direct interface with the system. It provides a map view and allows the user to search for and select facilities. The initial version was implemented before we rigorously followed the software process and does not have a design document.

COORDINATOR

The Coordinator performs target system analysis. It coordinates flows between several models, using the micro-economic model described in Section 2.

OPTION GENERATOR

The Option Generator proposed direct targets to achieve a set of desired effects. These are displayed in the Target Set Tool for the user to approve.

Interfaces

There are two external interfaces to the Endstate system. These are with the SDT Plan Editor and with the MIDB.

SDT PLAN EDITOR INTERFACE

The Coordinator communicates with the Plan Editor by XML messages. The Option Generator receives XML messages from the Plan Editor and sends XML messages to the Target Set Tool. The Target Set Tool communicates with the SDT through direct function calls, passing Java objects.

PLAN EDITOR/COORDINATOR INTERFACE DATA

Message	Description
PLAN	Relevant subset of the plan stored in the SDT
TARGET	The direct, indirect, no strike and no effect targets
AUGMENTATION	Repeats the plan message, augmented with information from the TSA simulation

PLAN EDITOR/OPTION GENERATOR INTERFACE DATA

Message	Description
PLAN	Relevant subset of the plan stored in the SDT
TARGET	The direct, indirect, no strike and no effect targets

OPTION GENERATOR/TARGET SET TOOL INTERFACE DATA

Message	Description
PROPOSED TARGET	List of targets proposed by the algorithms and links to the plan.

COORDINATOR/TARGET SET TOOL INTERFACE DATA

Message	Description
SOLUTION	Simulation results for display in Map Tool.

TARGET SET TOOL/PLAN EDITOR INTERFACE DATA

Message	Description
Collection of facilities	Facilities that are on the direct, indirect, no strike or no effect lists.
Facilities Event	Facilities selected by the user on the direct, indirect, no strike or no effect lists.
ACCEPTED TARGET	List of targets and links to the plan, proposed by the algorithms and accepted by the user.

6 JEFX 04 SUPPORT

6.1 Summary of EBO EndState Results from JEFX

EBO EndState-JEFX04 Environment Conditions

EBO EndState capabilities were provided at JEFX04 as part of the overall EBO initiative conducted within the strategy cell division. Since targeting decisions are not the function of the strategy cell, the extent to which EBO EndState capabilities could be used or evaluated was limited by the process hierarchy conducted within the strategic planning operations. EndState capabilities were further limited by data availability. Recall, EBO EndState provides targeting support and analysis for Effects-Based Planning Operations in three distinct forms: automated target option generation, target-systems analysis and manual (map and or query based) target identification and selection. As stated above, the automated targeting capability (Option Generation) and the Target Systems Analysis (TSA) capabilities require sufficient Enemy Order of Battle information in order to execute the algorithms. Data availability limitation for various JEFX events was as follows:

In Spiral 2, the link data was sparse. There was good connectivity between producers and transshipment facilities within each network. However, consumer facilities were missing and cross-network links were absent. As a result, TSA was unable to function and Option Generation was required to work in a limited mode.

For Spiral 3, many of the POL facilities were repositioned. As a result, many links would cross much of Califon and reaching a particular node might traversing a path much longer than the dimensions of Califon. Additionally, there were difficulties configuring the software since we had only one CPLEX license and multiple machines that would have wanted to use it. Eventually, we were able to use Option Generation well using the nodes-only capability.

At Main Ex, several different units were used for the capacity values. As a result, the network was artificially constrained to have very little flow. The issue with the long links from Spiral 3 remained. (This did not cause problems for the software, but it did represent an unrealistic network. As a result, some results were counter-intuitive if one assumed a reasonable structure for the networks.)

EBO EndState Training Results

As part of each JEFX Spiral and Main Ex., users and assessors received training on EBO EndState capabilities as part of the SDT training activities. Lessons learned from the JEFX training sessions point to the need for more individualized training and a more favorable training environment. SDT training for JEFX04 was conducted in a noisy environment with trainees attempting to follow training directions via a headset communication system. A typical training class consisted of 10-15 trainees under the direction of a single tutor. While ALPHATECH provided additional training facilitators to answer questions, it was difficult for participants to catch-up with the training after suffering a fall-back. In addition to high trainee/tutor ratios, there was an issues or participant interest. While some trainees required instruction on use of the entire system, most users were focused on a specific task or function of the software. This made it difficult to hold the interest of the trainees. Future training sessions would benefit from more individualized training geared toward smaller groups and focused on activities that would be conducted by the group.

EndState JEFX Execution Results

While EBO EndState capabilities were limited by the absence of sufficient link data at JEFX04 overall assessment of the product was very positive. Individual demonstrations of EBO EndState capabilities were presented to various members of the Targeteering contingency. Demonstrations included an overview of unavailable capabilities for automated target generation and analysis as well as Node based Option Generation and Manual Targeting capabilities. Feedback from targeteers drew positive comments in that EndState capabilities reiterated many of the capabilities of NASIC's Tel-scope Tool. In addition, EndState capabilities were praised for their ability to extend to multiple target systems whereas Tel-scope applies to communication systems only.

High level VIP demonstrations of EndState capabilities and SDT in general drew praise from several sources. Gen. James (Head of the EBO Panel for the C4ISR Summit) and Col. Casserino were given demonstrations of the entire suite of EBO tools available at JEFX04. These individuals were truly impressed with the full scale integrated nature of the SDT suite of tools and the capabilities of EBO EndState in particular. Comments

by Col. Casserino indicated his recognition that SDT tool such as EndState and COG Articulator provided “real analysis capabilities under the hood” as opposed to other EBO products on display which “presented information but provided no additional analysis”. The capability to identify and analyze targets using EndState capabilities and then import those targets directly into the SDT plan was viewed as a key facilitator of Effects-Based planning.

The JEFX04 Main Ex. Branch planning activity was the first opportunity to use EBO EndState capabilities as part of the experimental process. While we reiterate, targeting was not a primary focus of the branch planning effort in the strategy planning cell, there was interest in viewing and assessing the EndState capabilities for target generation. As part of the branch planning efforts, participants Wing Commander Red Thompson and Tim Spath along with Maj. Dietrich and Maj. Greathouse developed plans to limit enemy capabilities in area X (detailed left out for classification purposes). A critical desired effect for this plan included denial of transport of materials to the area around X. These participants employed EndState manual targeting query and map capabilities to filter targets to display road and rail networks in the vicinity of X. They were further able to identify (through MIDB queries) chokepoints to effectively cut supply routes into X. Once identified, they exported selected targets into their plan under the appropriate effect artifact. These capabilities were viewed as very easy to use and beneficial for a seamless effects-based planning process.

Through these trials, EBO EndState was assessed in a positive manner. There was a general sentiment that EBO EndState capabilities would be a valuable asset to targeteers at future JEFX events. The primary criticism/suggestion to enhance EBO EndState capabilities centered around the map display. There was a sentiment among users that transitioning the EndState map display to the Falcon View mapping system would significantly increase its utility.

7 DARPA ENDSTATE WORK

7.1 Introduction

DARPA directed ALPHATECH to investigate approaches to understating the effects of operations as it pertains to the planning, execution, and assessment of military operations. This work took place in three distinct efforts, chronologically listed: Endstate, EBUNT, and FogLight. This summary focuses on the FogLight activity, as it is a culmination of the lessons learned from the first two volumes of work. As deliverables, we provided over two dozen separate PowerPoint presentations, consisting of hundreds of slides to the DARPA Program Managers (PMs). As such, this section will summarize the literature reviewed and analysis performed in the construction of the briefing materials provided to DARPA. The final EBUNT and FogLight presentations are provided in appendixes D and E respectively. These presentations effectively summarize the results of all three Efforts.

7.2 Problem Refinement

At the Direction of our DARPA PM, Mark Greaves, we focused our 2004 COG modeling efforts on the cognitive aspects of planning, execution, and assessment. Leveraging the previous Endstate work in reduced ordered modeling and time scale-scale decomposition, we developed the FogLight concept, highlighting the role of human decision making.

FogLight addresses the adaptation of the endstate analysis into information presentations, which promote quick and accurate command decisions. As evidenced in the January 2004 Future Combat System (FCS) Command and Control (C2) experimentation at the CASCOM Battle lab, the warfighter is hard pressed to interpret composite endstate models and projected scenarios in real-time with current C2 displays. Mark Greaves identified the endstate visualization problem as the most crucial part military planning, execution, and assessment, because the final decisions drive the modeling and algorithm development. Because battlefield stress and the “fog of war” make traditional User Interfaces (UI) ineffective, the warfighter needs interfaces capable of presenting the most salient portions of a model and predicted effects into his current frame-of-reference. Therefore, the FogLight work focuses on Warfighter Machine Interfaces (WMIs) that adapt endstate models to the context and the individual.

The FogLight vision is to create:

- Decision support tools customizing themselves to user, role, device, and Knowledge Base (KB), resulting in faster, more accurate decisions in unfamiliar contexts
- Effective UIs for dynamically composed C2 software systems

The FogLight approach is to:

- Apply recent advances in diagrammatic reasoning research to develop a system that dynamically generates user-specific interfaces (UIs) according to each user's role, cognitive style, and available display hardware
- Develop a principled means for combination of UI elements, mapping key domain dimensions into appropriate interactive displays, and preserving the most valuable information in a readily-understood form
- Combine the advantages of current paper-based planning collaterals, such as maps and sketches, with automated inference processes that dynamically generate interface displays based on knowledge of the task and domain

The FogLight concept anticipates the following benefits:

- Improved human cognitive capabilities across all applications
  - Reduced time on task by compressing inference steps, Example: search as direct perception
  - Reduced user-system interactions. System generates interfaces that are likely to contain the internal structure of the solution
  - Improved support for complex coordination across multiple battlefield functions. Example: Dynamic joint replanning involving logistics, communications, air-strike, and ground forces
- Shortened development timelines by raising the level at which GUIs are specified
- Lowered barriers to adoption of automated C2 systems
  - Reduced training time. Direct encoding and task-based UI generation lower learning curves.
  - Reduced training costs and staff requirements for new systems

7.3 Concept of Operation Development

With the new emphasis on model abstraction for effective decision making, we were tasked to investigate a wide variety of C2 domains, best illustrating the benefits of technological leaps in this area. We produced a series of briefings which presented

potential military problems, operational challenges, and anticipated impact. The C2 applications include:

- Diagrammatic Coordination of Urban Operations
- Sketch-based Situation Monitoring and Replanning
- Planning and Control of FCS Robotic Assets
- Using Diagrams to Find the Right Questions for Intelligence Analysis
- Diagrammatic Special Ops Planning
- Airborne Command and Control (AWACS)
- Logistics Routing
- Weapon Target Pairing

See **Appendix A** for the problem descriptions and reasoning approaches for these application domains.

By taking some of the most challenging attributes of each domain, including dynamic replanning, handheld devices, battlefield stress, and rapid decision making, we formulated a detailed scenario to help guide the modeling and algorithmic framework. We combined field reports from Operation Anaconda, Operation Iraq Freedom, and field manuals to construct a use case for the FogLight system: **Non-Regular Enemy Force Attacks Exposed Logistics Operations** (see **Appendix B** for several slides illustrating the scenario using operational graphics). We gathered several screenshots from many current and Next Generation C2 systems, including the following:

- TBMCS air operations planning and execution
- FCS Warfighter-Machine Interface current concepts
- BCS3 next generation Logistics situation awareness, planning, etc
- FCS Unit of Action Communications Networks concepts

We analyzed these screens for cross-COG models, adversarial representation, human decision points, input requirements, state estimation, simulation, and projected impact

capabilities. The FCS Warfighter Machine Interface (WMI) requirements stressed the following constraints on display of information:

- WMI system generates all GUIs from UI specs passed by mission applications
- Tailor displays to user role, authorization, and preference
- Field operation in C2 vehicles, finger selectable, non-cluttered displays
- Common look-and-feel across all UIs
- Warfighter centric

These WMI requirements proved quite useful in framing the visualization architecture for Endstate models and algorithmic results. From the CASSCOM Battlelab FCS C2 experimental results we identified a number of outstanding needs:

- Enhanced visualization and dissemination of the tactical scheme of maneuver enables effective collaboration (FCS C2 req)
- Decision tools need support integrated battlespace management of the battlefield functional areas (FCS C2 req)
- Tactical decision making requires a running estimate that provides a continual flow of actionable information, predictive intelligence, visualization, and presentation capabilities (FCS C2 req)

We combined the analysis of existing systems, FCS WMI requirements, and outstanding operational needs, into a detailed scenario specifying Army Universal Task List (AUTL) tasks performed by a number of military component in our identified use case. In Figure 7, these steps are organized into categories of "Observe, Orient, Decide, and Act," otherwise known as the OODA loop.

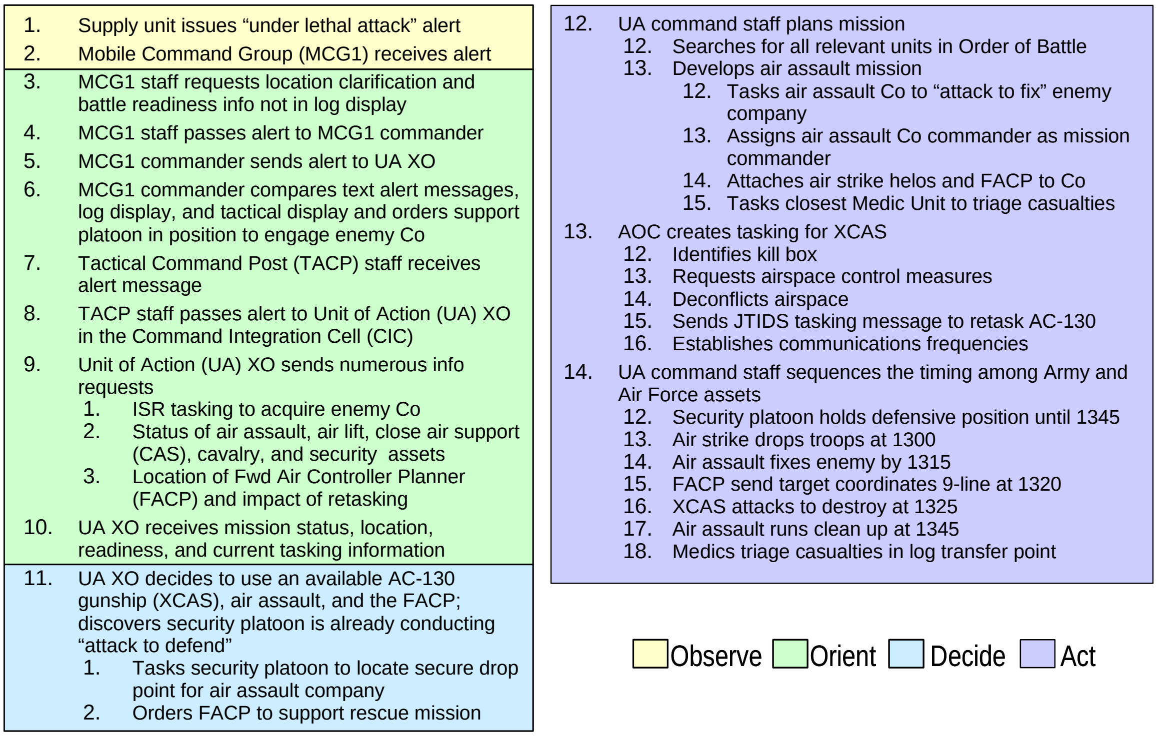


Figure 9 – These steps detail the tasks performed by a number of elements during a joint operation where dynamic replanning is required due to an unanticipated flank attack.

By constructing these steps, we were able to construct metrics for measuring replanning activities with and without a FogLight-type systems (an explanation of the metrics framework is covered in the attached FogLight briefing). The technological underpinnings for a FogLight concept are described in the next subsection.

7.4 Technical Results

With the FogLight approach and detailed use case defined, we refined our modeling approach by elaborating the cross-COG model transformation steps underlying each step in the scenario. This work resulted in a literature study of relevant fields, development of a FogLight architecture, and the construction of candidate UIs resulting from the various transformations.

The approach to FogLight draws from fields such as Diagrammatic Reasoning, Geographic Information Systems, dynamic control theory, collaborative agent architectures, knowledge-based systems, cognitive science studies (pre-attentive recognition), and heterogeneous logics. See **Appendix C** for a summary of the findings from our literature survey on model abstraction for effective decision making. We

constructed a broad program architecture for FogLight in which technological components can be developed. The FogLight system architecture is depicted in Figure 10.

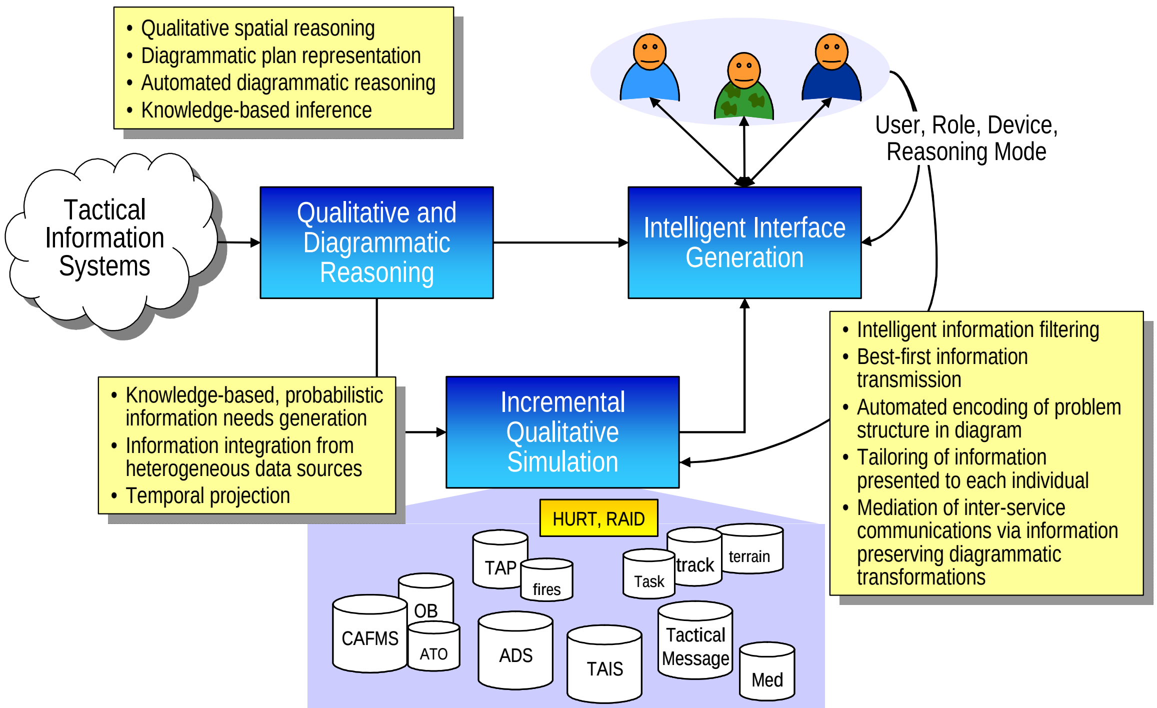


Figure 10 — The FogLight system architecture consists of three general components: 1) the Qualitative and Diagrammatic Reasoning module performs state estimation to reason about plan sketch elements, 2) the Qualitative Simulation module is responsible for prediction and causal reasoning, and 3) the Intelligent Interface Generation module transforms the COG models into UIs by emphasizing the most salient effects.

The FogLight system architecture is intended to help develop a DARPA program to build a context-aware information system. Conventional interfaces are minimally aware of the device, user profile, current task, and critical data elements. There is a lack of scientific foundation for the effective dynamic generation of visualization and UI elements. The FogLight concept focuses on role-specific interfaces, as shown in Figure 11, which produce plan sketches, situation monitoring, command direction, and predicted outcomes for an individual context.

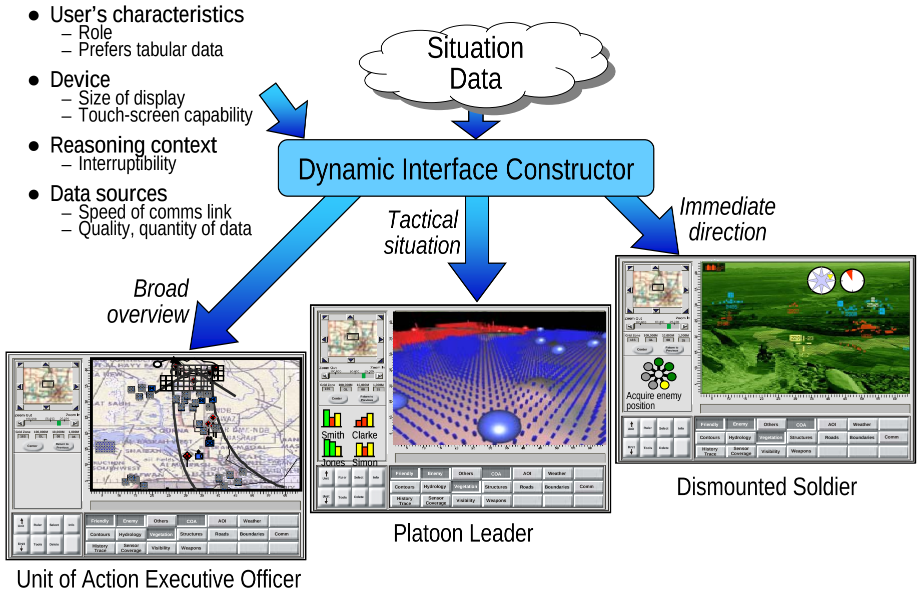


Figure 11 —The FogLight architecture uses simulation, diagrammatic reasoning, and UI generation to produce role-specific interfaces for different echelons and tasks.

The technological challenge presented by the FogLight architecture is to determine the principles for mapping situation data to interfaces. In essence, finding the appropriate model abstractions and transformations between terrain and tracking data, plan and task orders, and visualization and GUI compositions. We decomposed this problem into three constructive research goals reflecting the system architecture:

1. Provide a basis for constructing a general, provably correct system of information transformations, forming the basis of each architectural component, by exploiting advances in logic for describing mappings between semiotic systems.
2. Determine the choice among otherwise valid structures based on current context, by applying recent findings from cognitive research on human perception.
3. Develop general principals for mapping situation data to useful interfaces, committing to a recognizable structure, composing UI elements (e.g. windows, menus, toolbars, etc), and formats (e.g. tables, bar charts, graphs, etc.), by applying advanced UI research in task models and device independent GUI frameworks.

We also developed a candidate functional architecture, pictured in Figure 12, to illustrate the information flow of a FogLight context-aware information system.

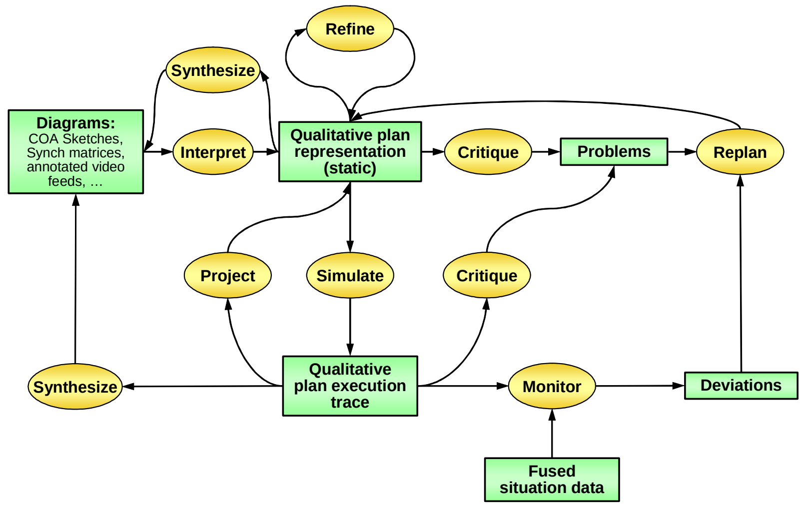


Figure 12 — The FogLight functional architecture shows the information flow of a context-aware systems with processing stages shown as yellow ovals and output artifacts shown as green boxes.

FogLight replies on a specific formulation of Situational Awareness (SA) to ground its models in psycho-physiological limitations of human-computer decision making and a hybrid-reasoning model which combines diagrammatic and propositional models to ground FogLight transformations in logic formalisms.

First, we summarize our model of Situational Awareness. The FogLight SA model, including on the latest version of the Unit of Action Operational and Organizational Plan, builds on the Endsley's approach to mental modeling:

- Perception of elements in the environment within a volume of time and space, include number, location, and capabilities of all enemy and friendly forces in a given area and their relationship to other points of reference.
- Comprehension of elements meaning, the capability to identify patterns and develop an integrated picture of the environment – the first level at which the decision-maker moves from awareness to understanding.
- Projection of their status in the future; the definition of the future actions of the perceived elements in the environment.
- Technical (What's there and what is *not* there)
    - Location. Where is the entity? Perceived truth (unusable, actionable, targetable)
    - Acquisition. What is the entity? (detected, classified, and id'd)
    - State. Entity health? Mission capable status (alive, hit, dead)
- Cognitive

- Location relative to points of interest (blue/red, civilians, built up areas, etc.)
- Acquisition. What are they capable of doing (range fans, munition footprint, etc)
- State. Entity health and weapon status (fully armed, fueled, disrupted, etc)

Next, we present our hybrid reasoning model, in Figure 13, which builds on the research of Goguen and Harrell (2003), Garagani and Ding (2003), and Barwise and Etchemendy (1995).

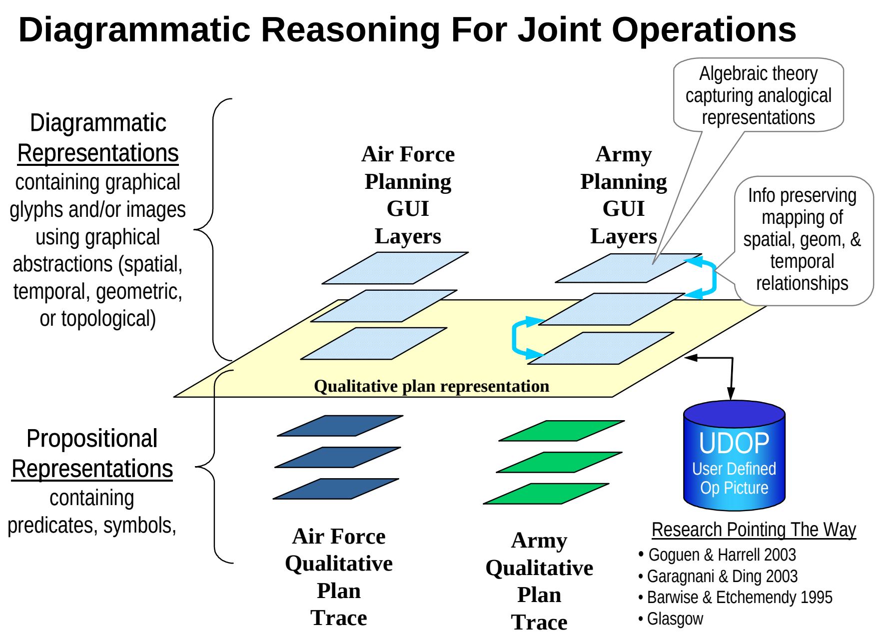


Figure 13 – The hybrid model reduces inference scalability short comings, such as in the ramification problem, by linking propositional logic with analogical reasoning via transformations among linked views.

Hybrid reasoning focuses on methods for combining diagram (analogical) representations and propositional descriptions, which can ground to provable semantics for a description of information equivalence. Some of the most promising work is done by Garagnani (2003), who has derived a formal hybrid framework, to obtain a 2 to 90 times speed up over classic planning approaches. This is the theoretic foundation for FogLight's context-aware computing. In the next subsection we present the results of using hybrid reasoning as applied to the problem of generating dynamic UIs.

Example FogLight Transformations

FogLight's Dynamic UI Generation draws from a body of work on automated generation of visual information, known as *automated design*. MacKinlay is the progenitor of this field, defining the concepts of expressiveness and effectiveness, but work continues today leading into hybrid reasoning through the analogical representations (discussed in the previous subsection).

Here we present a series of candidate information displays that result from the model transformation. These examples attempt to illustrate the challenges of automated design, particularly:

- Displays perform information preserving transformations among linked views enabling trade-off and constraint enforcement
  - Sketches and diagrams bridge communication gaps between military domains (Army, Air Force, Log, ISR, Comms, etc)
  - Implied tasks and information requests are inferred from UI elements through qualitative reasoning
- Aggregation of models produces visual information that considers the viewers' role, task, and cognitive situational context to assess the value ratio of information
  - User Modeling
  - Cognitive Task Analysis
- Hybrid representational frameworks automatically synthesize qualitative (diagrammatic/view) models from varied data-rich domains through spatial and topological composition processes
- Robust Automation: Nothing gets missed
  - Provable equivalence ensures the accuracy of abstraction steps
  - Displays are adapted by programming by example learning techniques

The first display (Figure 14) shows the type of information that may be displayed to an executive commanding (XO) officer during a dynamic replanning activity.

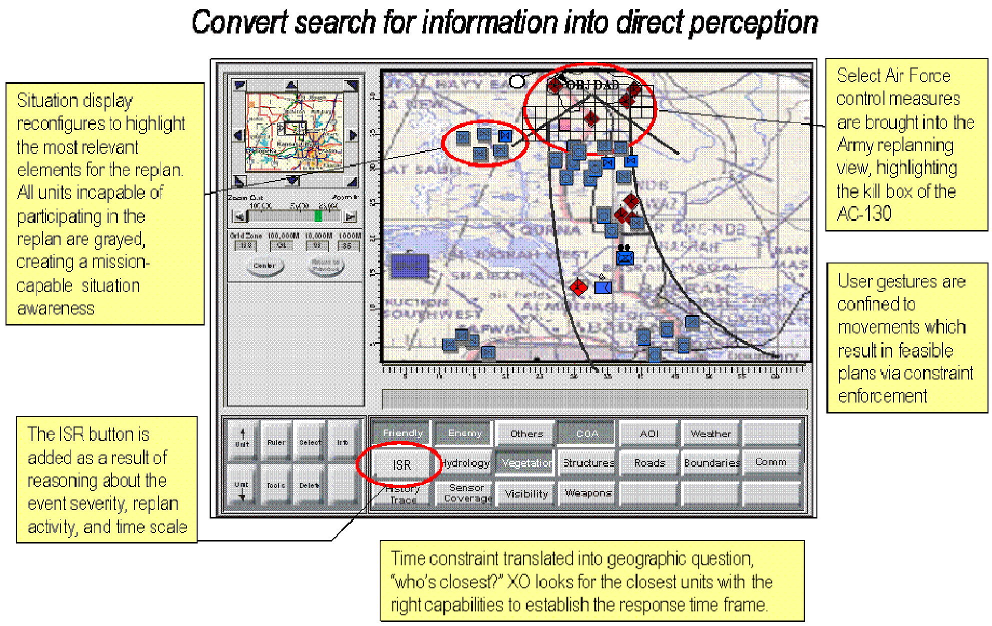


Figure 14 – The Unit of Action executive commanding officer (XO) information display aggregates multiple situation models, mapping to his current frame of reference (based on his latest plan).

This display utilizes a board-base of command experience, where decisions are often a quick recognitional process, like a chess master choosing from patterns of moves. On the other hand, a newly trained foot soldier may need some of the same information, but he must make quick decisions with less experience, so he need tasks clearly displayed with contextual guidance.

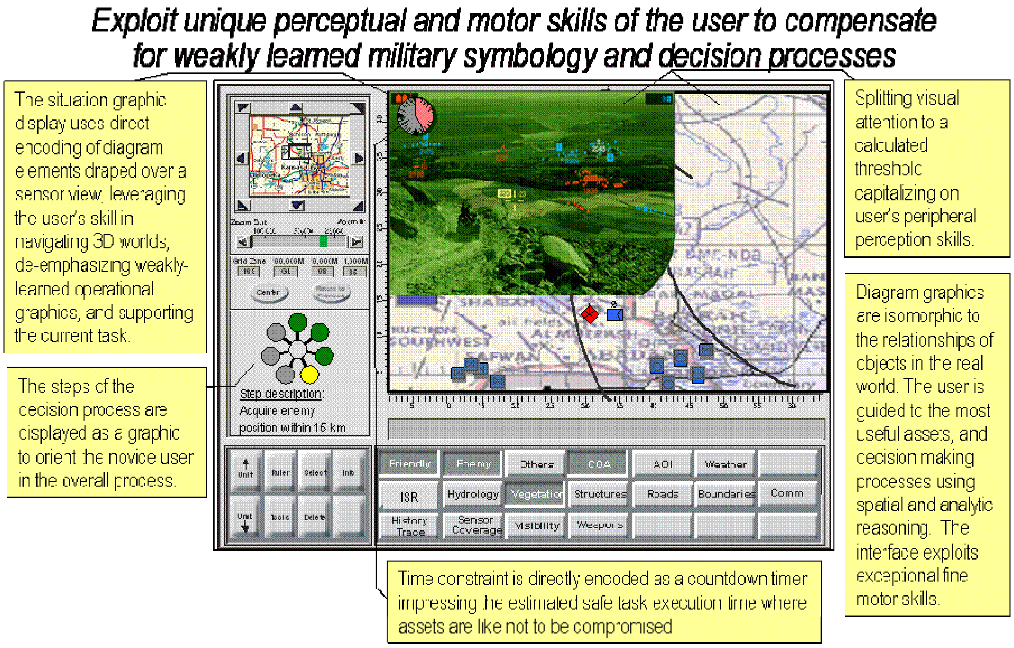


Figure 15 – A dismounted soldier's display is tailored to his modal preferences and current tasks, compensating for his limited experience with operational graphics.

Though the foot soldier is not thinking strategically, like the XO, he still requires the appropriate context to carry out the spirit of the commands if something unexpectedly goes wrong. In a different vein, coordination of joint operations is particularly challenging, as symbology, information displays, and task decompositions vary among the forces. Figure 16 shows an example of a display which synchronizes the information across military branches.

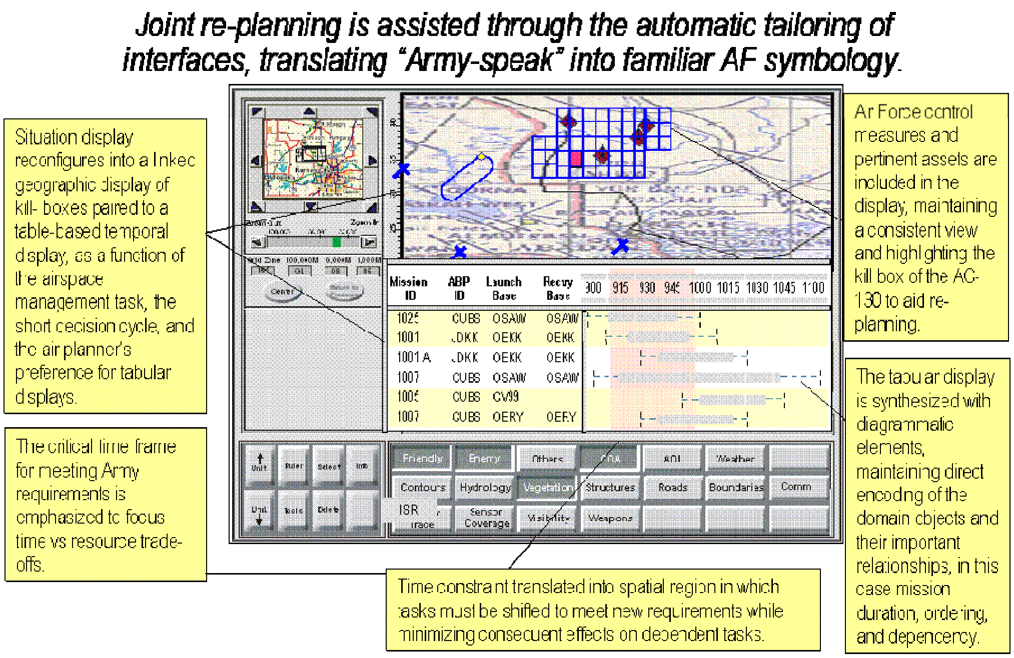


Figure 16 – An Air Force planner's information display translates Army operational graphics and chooses a gantt chart for the display of temporal information.

7.5 Conclusion

The rapid increase in capabilities and complexity of current and anticipated C2 systems will place comprehension of planned (endstate) effects on the critical path to designing decision support interfaces. Recent research has generated promising results regarding effective hybrid model abstraction techniques for state estimation and prediction, and cognitive science studies of human perceptual biases. ALPHATECH has development the FogLight concept, at the direction of the Endstate DARPA PM Mark Greaves, to establish the technical foundations, detailed use cases, and anticipated results from advancements in COG modeling, cross-COG transformations, and prediction of adversarial reactions and effects. ALPHATECH created a number of briefings to specify scenarios, architectures, candidate UIs, and a metrics framework to show how FogLight can go beyond the current state of practice, where systems only accommodate limited user and device variance, GUIs are hand crafted, and cognitive task modeling is labor intensive. The envisioned FogLight system will result in more accurate decisions under duress, lower the barriers to adoption of automated C2 systems, and reduce the development time for more effective interfaces.

7.6 Background

The first Endstate work began by looking into promising model abstraction techniques, which formed the foundation for FogLight's approach to planning, execution and assessment of Effects-Based Operations. In this subsection we include an abstract of the *Understanding EBO: Model Abstraction and Achieving a Favorable Endstate* briefing presented by Alan Evans at the Enabling Technology For Simulation Science V symposium.

Under the DARPA Endstate program, ALPHATECH has examined the problem of understanding the effects of operations on multiple, complex and highly interconnected networks within a nation-state's infrastructure. ***The unifying technical concept of much of the Endstate work is model abstraction***. Endstate has considered two basic forms of model abstraction in connecting models of different systems. The first is reduced-order modeling, an inductive approach to modeling aggregated problems in variable spaces of reduced dimensionality. The second form of model abstraction considered is time-scale decomposition, leading to hierarchies of related models, in what might be called a deductive approach. Model-based abstraction of network facilities and links, together with constraining physics, as well as the priorities and decisions of embedded operators or controllers, are planned for networks of interest.

Endstate work has been based on the following premises: (1) that models of critical systems such as electric power generation and distribution, transportation networks, telecommunications, etc., already exist at levels of resolution exceeding the foreseeable requirements of operational and strategic planning, (2) modeling dependencies among these sub-systems requires fundamental advances in modeling techniques, and (3) adding adversary reactions and workarounds as feedback to the models will demand a flexible approach, drawn from fields such as dynamic control theory, collaborative agent technology, neural nets and knowledge-based systems. Prototype work of some of these adversarial adaptive modeling techniques has been demonstrated this year under DARPA Endstate.

Concept development is also underway on the techniques that can be applied to assessment of causality and option generation in support of COA analysis. Daunting obstacles to progress include the sheer size of the range of outcome spaces and

combinatorial complexity of higher-order effects, and the fact that causality may not even be addressed by current models or supporting technologies. In the longer term, the paradigm of model abstraction and cross-connection of model hierarchies is being applied to concept development and prototyping in other domains. The models involved may be prototypes of system components being considered for acquisition, or conceptual simulations of future C2 and C4ISR systems.

APPENDIX A: FOGLIGHT APPLICATION DOMAINS

This section includes several summary slides for each military domain in which diagrammatic reasoning may provide substantial operational impact.

Plan Monitoring and Reasoning about Army COA Sketches

- Problem
  - **COP does not provide "big picture" for good decision making.** The COP is a large DB with thousands of relationships, streaming input, and largely textual or quantitative data. Human decision makers think in terms of strategy, tactics and plans.
  - **Humans can perceive relationship visually better than forming and scanning DB queries.** DB integration technology handles data distribution, normalization, and relational queries but is not well suited to present key information, such as multidimensional sources of change, which human can easily perceive visually.
  - **Replanning is difficult.**
- Approach
  - **Transform situational awareness data into projections onto COA diagram**. [Larkin & Simon, Barwise & Seligman] Diagrams automatically support a large number of perceptual inferences, easy for humans to do; [Larkin & Simon] Diagrams ease perception.
  - **Use diagrammatic comparisons to detect significant plan deviation**. [Barwise & Etchemendy] Diagrams can be used not only as a heuristic aid, but also for critiquing. Sound diagrammatic proof systems can be constructed.
  - **Use diagram-based HCI for replanning**. [Davies & Forbus] Diagram state alone is sufficient to transform analogous solutions to current problem; [Koedinger] Use of visual schemata can enable reasoning short cuts in problem solving; [Larkin & Simon] locality aids search. Reduction in number of symbolic matches required to evaluate options.

Planning and Control of FCS Robotic Assets

- Problem
  - **Tasking robots is significantly more complicated than tasking humans**. Planning and control of robotic systems involves more detailed commands and status monitoring. Robots have less ability to deal with the unexpected.
  - **Teleoperation doesn't work and doesn't scale.** Get rid of teleoperation without removing the visual aspect of it. The reduced visual display of the typical robotic asset make it difficult to understand status and take control actions.
- Approach
  - **Use information equivalence to transform human commands and robotic status**. [Ferguson & Forbus] Various general low-level perceptual

propositions can be linked with domain specific rule. High-level characteristics can be inferred to perform qualitative spatial reasoning.
  - **Explore efficient robotic plans via diagrammatic constraints**. [Chandra] Model-Instance Based Reasoning done with diagrams promote inductive leaps or "warrants for generalization" to derive general propositions from concrete instances; [Goel, 1995] Human problem solvers exploit diagram vagueness to discover effective solutions; [Davies & Goel] Visual analogies aid problem solving
  - **Project diagram elements into robotic sensor display**. [Davies] Diagram state alone is sufficient to transform analogous solutions to current problem; [Koedinger] Use of visual schemata can enable reasoning short cuts in problem solving

Using Diagrams to Find the Right Questions for Intelligence Analysis

- Problem
  - **Information Overload** Intelligence analysts read hundreds of reports a day, looking for patterns of activities akin to searching for fragments of needles in multiple haystacks.
    - ♦ This seems like more of visualization problem. This type of pattern matching is not trying to make implicit information explicit.
  - **Collaborative analysis is complicate by distributed reports** The “big picture” of an analytic line is often spread over a multiple of shorter inter-dependant documents. Analysts often have no time to write a comprehensive summary analysis.
  - **Classification management and source tracking is time consuming** Because an analysis is distilled into text, the contributing evidence (and its attributes) is not wholly retained. Source attribution and declassification activities are costly because no robust linkage to original data. This detracts from focusing on the analysis.
- Approach
  - **Information equivalence enables the diagrammatic construction of analytic queries** [Chandra] Problem solving is driven by the most relevant info in any domain. The interplay between spatial and non-spatial predicates enables opportunistic solution discovery.
  - **Use diagram-based HCI to capture an analytic line** [Yan, Forbus, Gentner] Theory of re-representation in match making through detecting opportunities, generating suggestions, and strategies for controlling re-representation.
  - **Spatial propositions contribute to the generation of intelligence requirements**.

Diagrammatic Special Ops Planning

- Problem focus: Reducing the time to construct robust plans in the face of compressed timelines
- Afghanistan Scenario: Lead time for SOF missions greatly compressed from doctrinal planning cycle (96 hr -> 24 hr) which could lead to greater mission risk and compromised plan quality

- Defense payoff : Reduce turnaround time between JSOCC MITASK generation and SOF MICON/MSR development
- Technical Challenge : Respect feasibility of complex, interlocking planning constraints
  - Spatial
  - Temporal
  - Resource
  - Capability
- Enabling Technology : Diagrammatic reasoning formalism
  - Visually encode different constraint types in a collection of diagrams
  - User views and constructs plans within alternate constraint perspectives

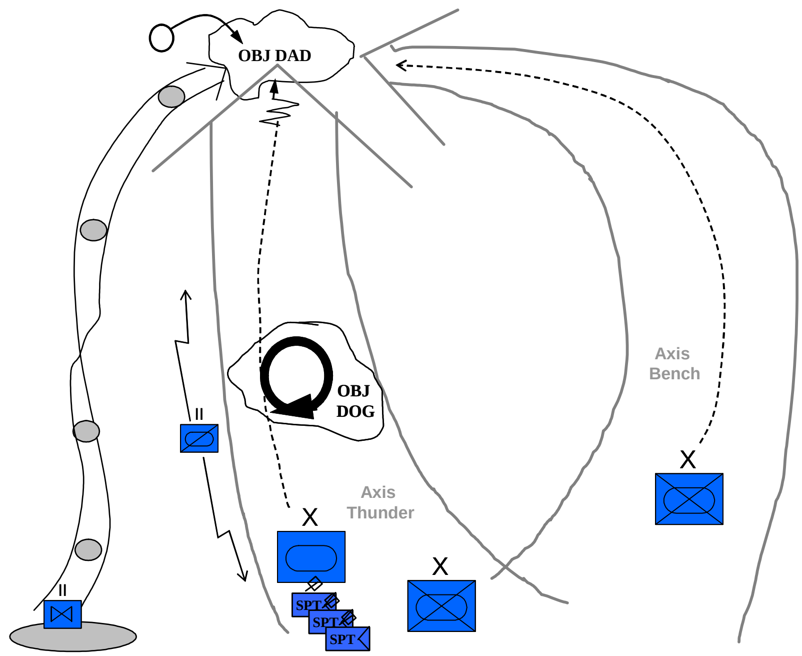
APPENDIX B: DETAILED USE CASE

Detailed Use Case: Non-Regular Enemy Force Attacks Exposed Logistics Operations

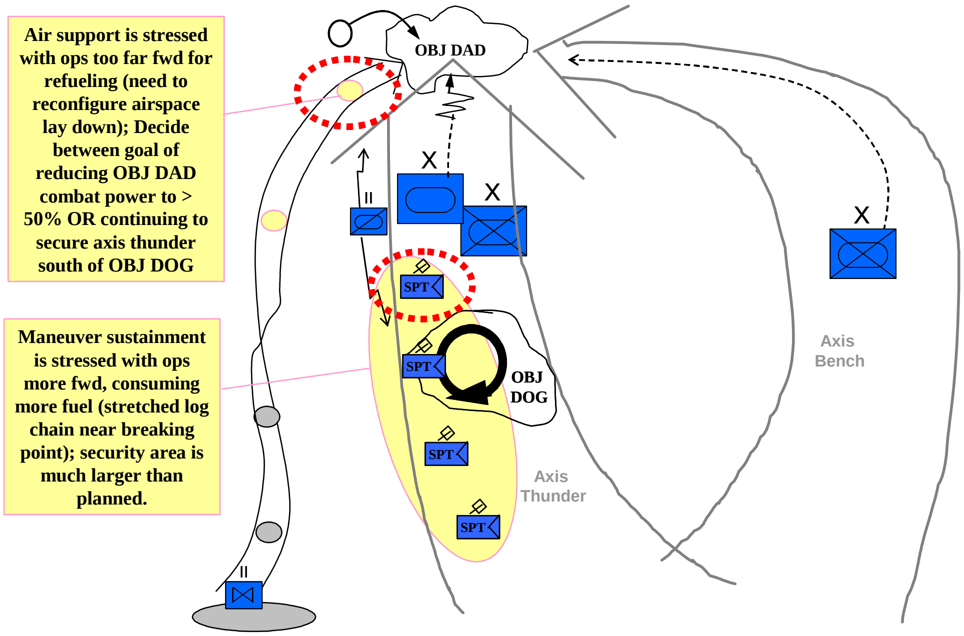
Situational Awareness and Dynamic Replanning
Enabled through Information Equivalence
Transformations Among C2 Displays

Operation Iraqi Freedom-like Scenario:

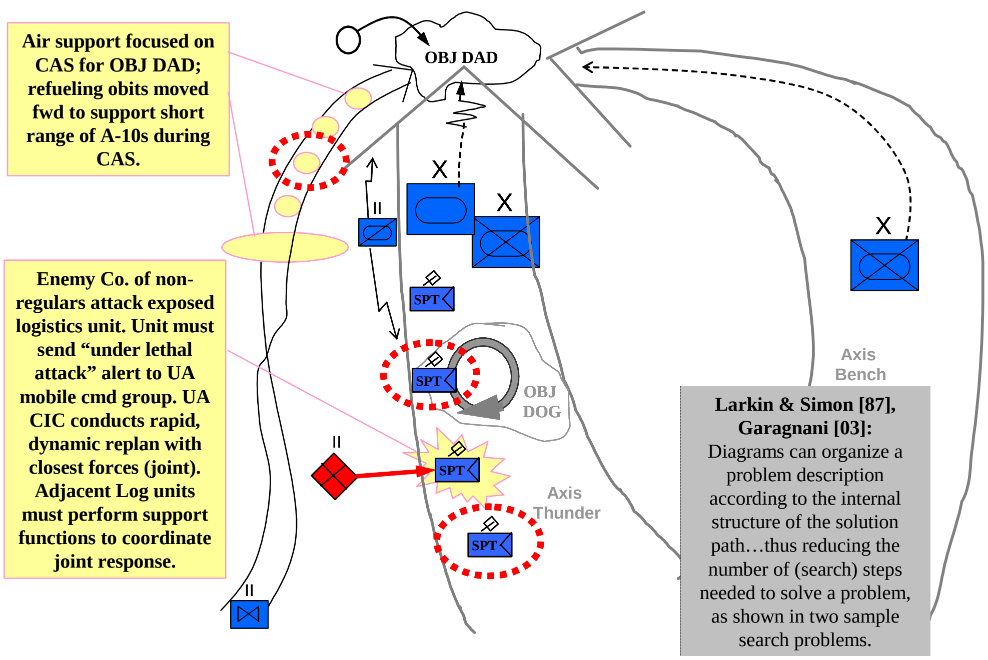
Attack to Secure OBJ DOG, Attack to seize OBJ DAD



Unanticipated Progress: Ground attack out pacing air support and logistics



Enemy Attacks Weak Point in Support Operations



APPENDIX C: LITERATURE SURVEY

ALPHATECH was directed by Mark Greaves to develop the FogLight concept leveraging recent advances in diagrammatic reasoning, cognitive science studies, and heterogeneous logics. The following is a brief summary of our findings.

- Graphical Excellence (Tufte)
  - Well-designed presentation of interesting data – a matter of substance, of statistics, and of design
  - Complex ideas communicated with clarity, precision, and efficiency
  - Givers the viewer the greatest number of **ideas** in the shortest **time** with the least **ink** in the smallest **space**
- Computational Synthesis of graphical presentations (Mackinlay)
  - Expressiveness – conveying all of the facts and only those facts
  - Effectiveness – Use of visual predicates that humans are better at perceiving
    - Small multiples (sometimes referred to as an **icon** or **graphic cluster** or **glyph**)
  - APT system uses the generate-and-test method
- Semiotic Morphisms (Goguen)
  - Preserve structure rather than content when a trade-off is forced
  - Preserve high level types over ordering rules of sign construction
- Goguen & Harrell 2003
  - Used algebraic abstract data type theory to define *semiotic morphisms* providing information preserving transformations between representations
  - Applied theory of info visualization to measure quality of several concrete examples, identified general principles
- Garagnani & Ding 2003
  - Developed hybrid (analogical/propositional) representational framework for planning avoiding classic limitations
  - Observed 2 to 90 times speed up solving classic planning problems such as Blocks World and Eight-Square
- Glasgow & Malton 2003
  - Applied array theory to capture spatial relations as symbolic arrays
  - Observed computational benefit from the implicit representation of spatial and topological constraints
- Other work
  - Barwise & Etchemendy 1995
  - Fobus & Gentner (Davies) theory of rerepresentation to generate suggestions based on a library of general methods, with strategies for controlling the process

APPENDIX D: DARPA ENDSTATE EBUNT BRIEFING

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EBUNT Briefing

Project Manager: Eric Jones
Project Lead: John Everett
August, 2003

Cities are the New Battlefield

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"The future of warfare lies in the streets, sewers, high-rise buildings, industrial parks, and sprawl of houses, shacks, and shelters that form the broken cities of our world..."

Ralph Peters, *Fighting for the Future: Will America Triumph*?

- Successful employment of force requires a detailed understanding of a complex and rapidly evolving environment
  - Buildings
  - People
  - Infrastructure
  - Resources
- Current urban ops planning tools
  - Lack high-fidelity, coupled models of indirect effects
  - Do not incorporate ISR tasking to update or deconflict model parameters
  - Lack indicators for alternative opponent courses of action
  - Do not consider 3-D urban environment
- Goal: Rapidly develop, update, and exploit dynamic models of centers of gravity (COGs) for effects-based tasking order (ETO) development in urbanized terrain

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Problem: Attrition-Based engagements in Urban Ops

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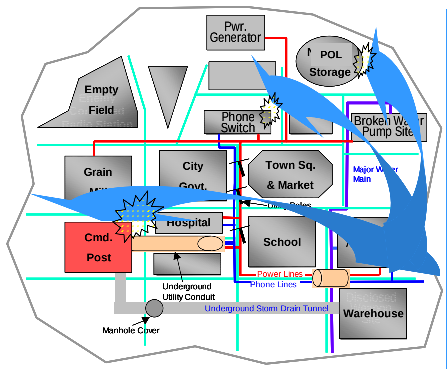
Today's engagement planning support tools were not developed for urban warfare and produce attrition based COAs….and have the potential to produce a multitude of negative effects & ROE contradictions



Commander's Intent: Destroy militia command outpost in Militacity

Rules of Engagement: Protect civilians and urban infrastructure

Combined Operations Intel Center: Outpost located in bottom left sector of city of 10,000
No other known red targets

Typical Attrition Based COA:
- Precision fires on Cmd Post, Coms & POL Storeage
- Occupy positions of advantage at Cmd Post, Coms and POL storage
- Tanks assume support-by-fire positions
- Dismounted infantry engage enemy from covered route
- Clear the building and consolidate
- Continue operations

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Three Technology Opportunities for Urban Operations

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- Situation Report Fusion
- Maneuver and Targeting CoA Analysis
- Urban Effects-Based Target Development

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Situation Report Fusion

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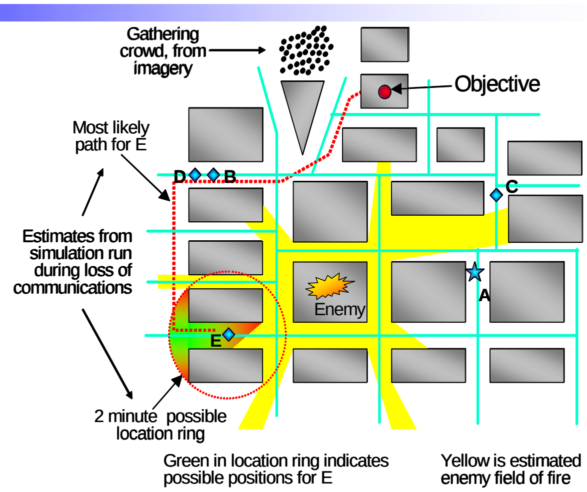
- Distributed, mobile sensor/comms net
- Form World State Hypotheses:
  - Friend and Foe locations
  - Structural damage
  - Obstacles
- Comms Management
  - Re-establish contact with unit, sensors
- Possible Worlds Visualization



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Information Requirements for Urban Operations

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- Mobility
  - What are all the routes across this river within the inner city?
  - What are our viable ingress/egress options from this neighborhood?
  - Have we isolated this building?
- Model construction and querying
  - Build a network model of the electric power grid
  - Find all the power plants in this city
  - Identify all the buildings in this neighborhood
- Tactical targeting options
  - How can we cut electrical power to this city block?
- Activity and threat identification
  - Notify me of changes in the environment that could impact my plans
  - Where might the friendly squad be that we lost contact with three minutes ago?
  - What about the enemy platoon that we observed five minutes ago?
- Plan critiquing
  - Can I flood this tunnel? Will flooding it achieve my goal?

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Complicating Factors

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- Answers to these questions often change over time
  - Snipers block best egress route
  - Enemy activity in building may indicate subterranean access routes
  - Newly rubbled building impedes access to electricity substation
  - New observation of enemy force location updates predictive estimate
- Answers to these questions are often uncertain
  - Based upon fragmentary data from multiple sources
- Answers are buried in a glut of information
  - Rapid change requires early recognition of emerging scenarios, threats
  - First indications of change may appear anywhere in the modeled area

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Limitations of Conventional GIS Systems

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- Provide inadequate fidelity for urban operations
  - Often outdated and inaccurate
  - Wrong scale and lacking in detail
  - Two-dimensional
  - Static
- Do not provide necessary support for model update
  - Cannot represent uncertainty regarding model structure
  - Cannot represent evidence pedigrees
  - Conventional vector GIS schemas (e.g. VPF) base representations on lines, points, and regions, and have no notion of object/relational structures
- Have no representation of capabilities, plans and goals
  - Warfighters must superimpose their knowledge of plans and objectives on the information

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Proposed New Capability

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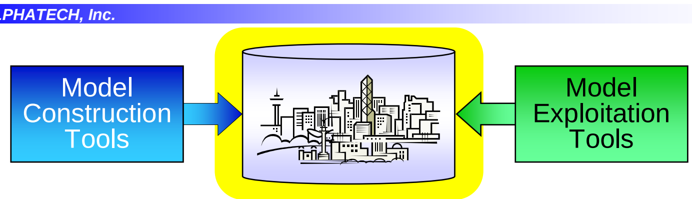

High-fidelity urban model

- Registered geospatially
- Assembled from multiple information sources
- Encompasses 3D representations of spatial features
- Evolves over time in response to intelligence
- Supports a uniform probabilistic framework
  - Assimilates new information
  - Maintains pedigree for fusion and visualization
- Contains multiple layers of information

Layers of Representation

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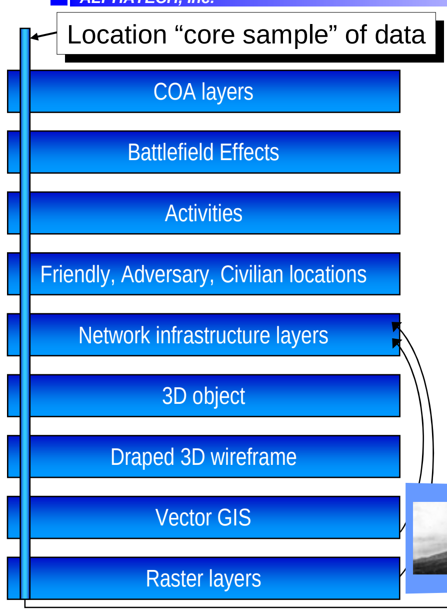
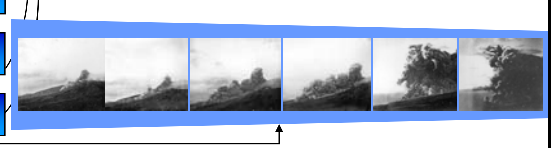


- Layers may be partially derived from other layers
  - Infrastructure layer from GIS data, imagery
- Queries can access an arbitrary subset of layers
  - Probabilistic framework fuses information across layers
- Each layer can have temporal extent



Proposed New Capability

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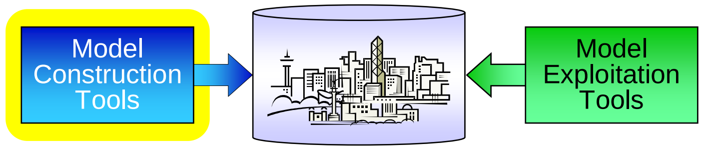

Data fusion and knowledge based tools for rapid model development and updating

- Legacy model import
- Georegistration for multiple spatially-distributed data sets
  - Vector GIS products
  - Blueprints
  - Imagery
- Multi-source fusion for automated model refinement/update
- Sketch-based operator input
- Ontology and probabilistic rule base for inferring most likely structure
- Rapid knowledge formation support for extending knowledge base
- Supervised and unsupervised machine learning

Proposed New Capability

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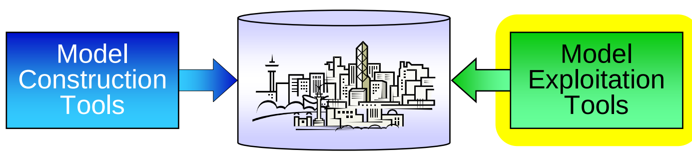

Tools for Rapid Situation Understanding

- Situation monitoring (*filter information, post alerts for users*)
  - COA evolution monitoring
    - Monitor force positions relative to objectives
  - Salient change detection
    - Explanation-based alerting
  - Activity identification
    - Enemy, civilian location
- Decision support (*query-driven, user-responsive*)
  - Network reasoning
    - Mobility analysis
    - Infrastructure targeting
  - Plan critiquing

What's New? Why Now?

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- First-ever large-scale geospatial knowledge base to incorporate explicit representations of time, uncertainty, plans, and goals
- Fundamentally new approach to developing, representing, and exploiting military geospatial information
  - Grounded in entity-centric representations, not points, lines, and regions
  - Designed for exploitation and model update
  - Integrates sensor-derived data with plan and goal representations
- Many of the necessary enabling technologies are in place
  - Scalable, object-oriented GISs
  - Fusion for 3D model creation
  - Knowledge entry tools
  - Knowledge representation
  - Probabilistic (Bayesian) formalisms for relational representations
  - Example-driven machine learning from imagery
  - Services-based architectures

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ENDSTATE Concept : Situation Report Fusion

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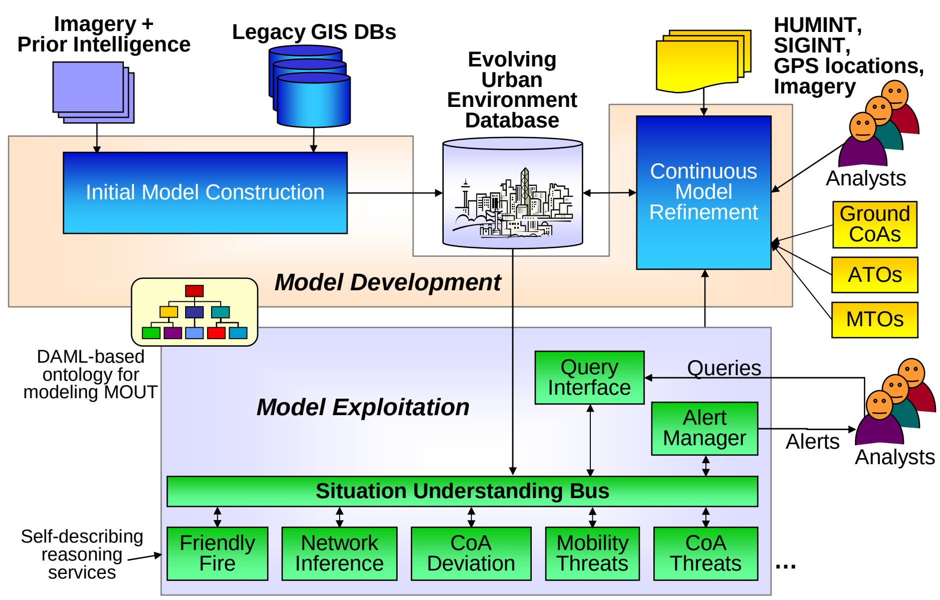

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Realizing the ENDSTATE Vision

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- COTS and maturing research systems provide the basis
  - GIS databases
  - 3D visualization
  - CAD model construction from imagery
  - Supervised machine learning
- Advances in data fusion and knowledge-intensive methods are essential for realizing radical new capabilities
  - Overcoming noisy or missing input data during structure modeling
  - Identifying key structural features of the terrain (e.g. major intersections)
  - Monitoring model evolution over time relative to plans and goals
  - Providing plan critiques and COA suggestions that combine the environment model with plans and goals

ENDSTATE: Inference Across Database Layers

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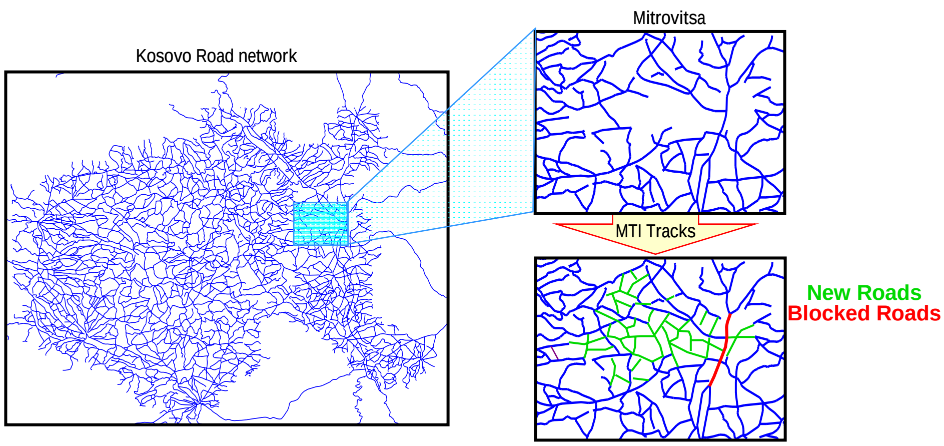
Using MTI track data to fill in gaps and correct errors in GIS road network information



ENDSTATE: Identifying Key Landscape Features

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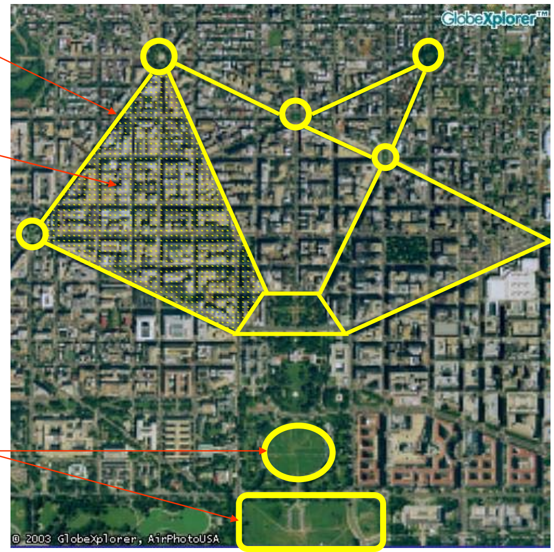
Major mobility corridors

Close-block orderly urban area



Several possible approaches
- Supervised machine learning
- Extract from GIS data
- Utilize urban area knowledge
  - Example: *Factories are unlikely in residential areas*

Open areas

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ENDSTATE: Situation Monitoring

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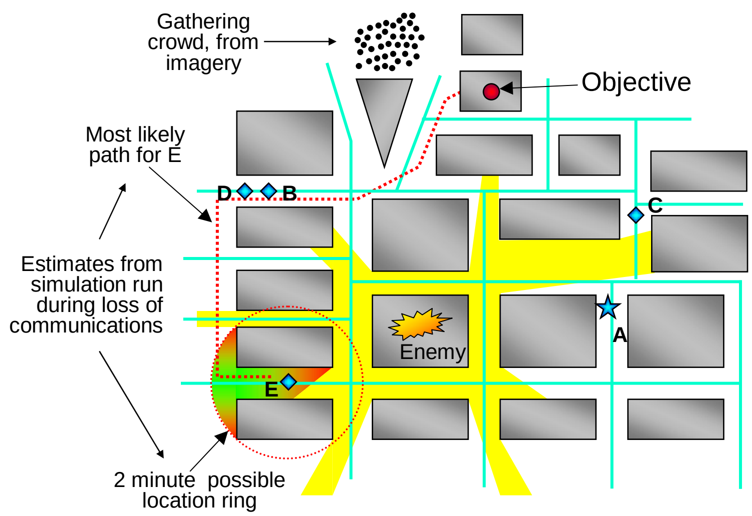

Green in location ring indicates possible positions for E

Yellow is estimated enemy field of fire

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Situation Report Fusion Summary

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- Information technology is on the brink of enabling radically new GIS-based situation understanding systems
- Challenging research efforts are required in
  - Data fusion
  - Image understanding
  - Large-scale knowledge-based inference
- Payoff will be systems that
  - Develop high-fidelity 3D models of geographic areas
  - Monitor unfolding events within these areas
  - React effectively to changes that may impact plans and goals

Maneuver and Targeting CoA Analysis

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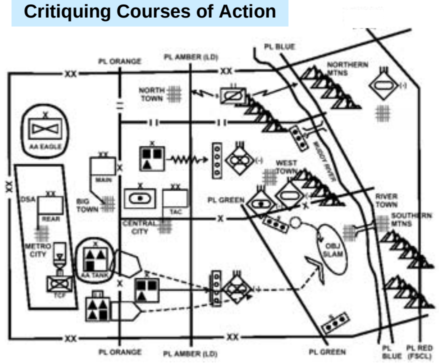
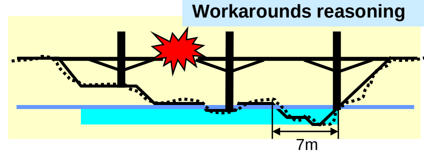
- Validate whether ground forces CoAs achieve their purposed effects
- Evaluate both maneuver and targeting CoAs for company echelon and below
- Suggest modifications to original CoA

Critiquing Courses of Action



Workarounds reasoning



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The Future of Urban Tactics

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- Common Operational/Tactical Picture
- DARPA SUOSAS
- C2 of Combined Arms Teams down to squad level
- Netted Fires
- UGV/UAV logistics, sensor, and fires platforms
- Enhanced mobility, maneuver warfare tactics

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Example: New Marine Urban Combined Arms CONOPS

ALPHATECH, Inc.

- Urban Combined Arms Company
  - 1 Inf company
  - 1 Tank platoon
  - 1 AAV platoon
  - 1 LAV platoon
  - Organic mortar and anti-tank capability
  - Eschew air support and long-range arty
  - Direct over indirect fire support
- Squad leader controls 2 fire teams and 1 tank team

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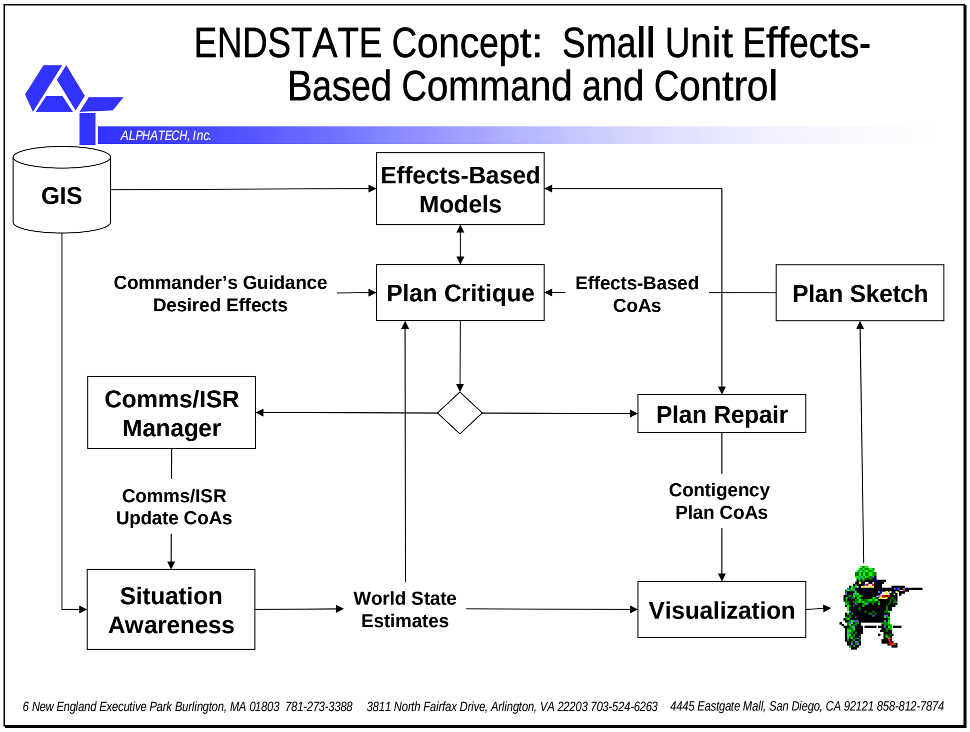
ENDSTATE Concept: Small Unit Effects-Based Command and Control
ALPHATECH, Inc.
GIS
Effects-Based Models
Commander's Guidance
Desired Effects
Plan Critique
Effects-Based CoAs
Plan Sketch
Comms/ISR Manager
Plan Repair
Comms/ISR Update CoAs
Contigency Plan CoAs
Situation Awareness
World State Estimates
Visualization
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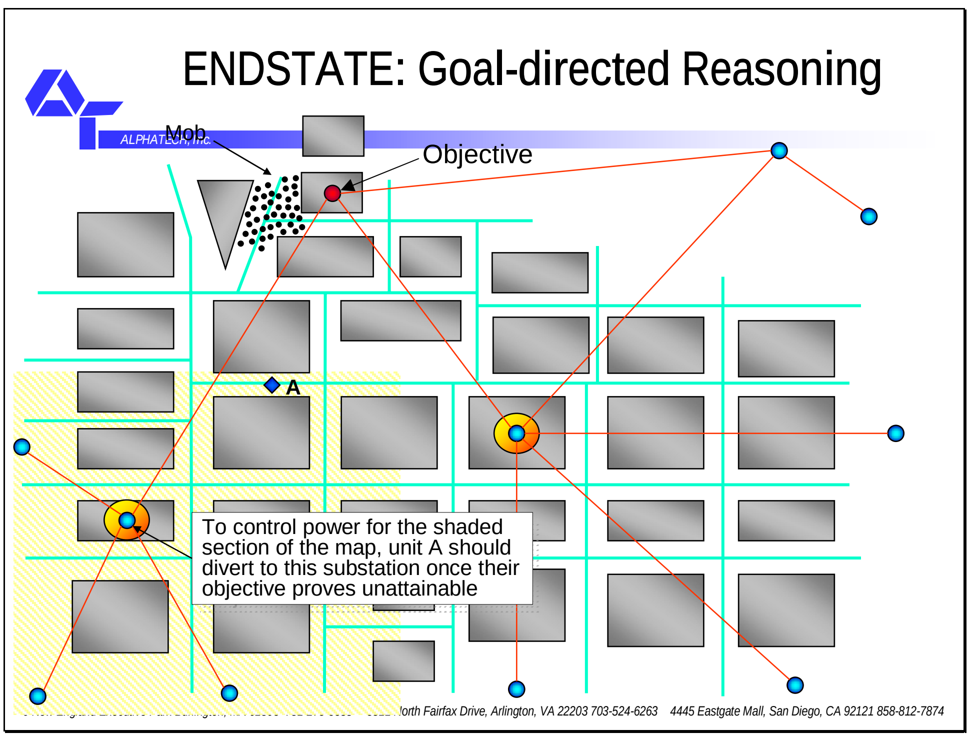
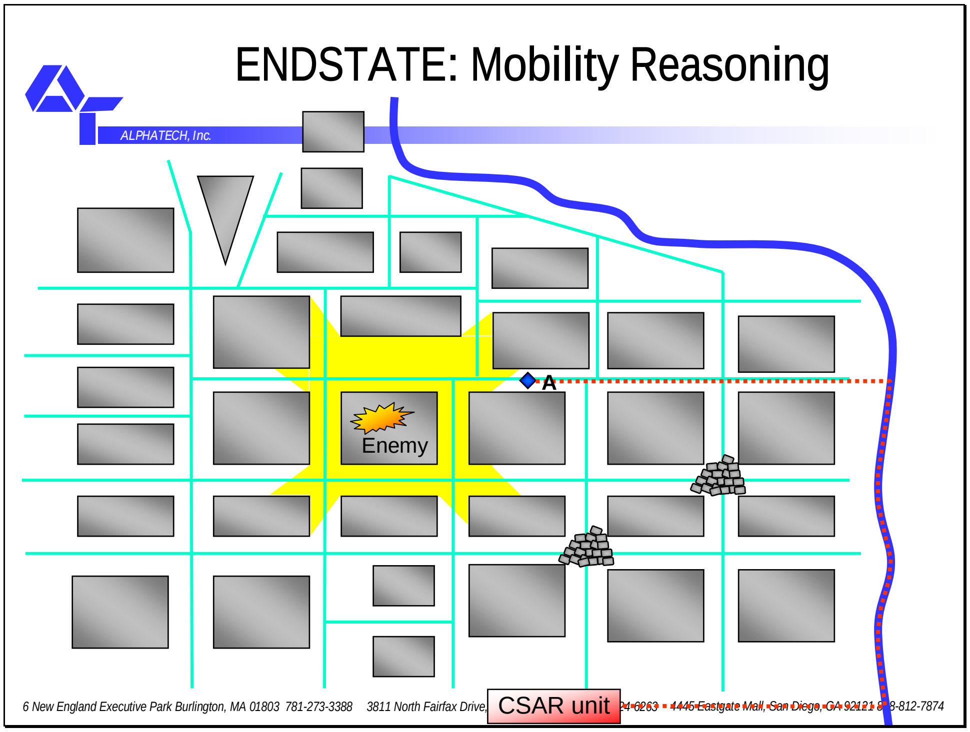
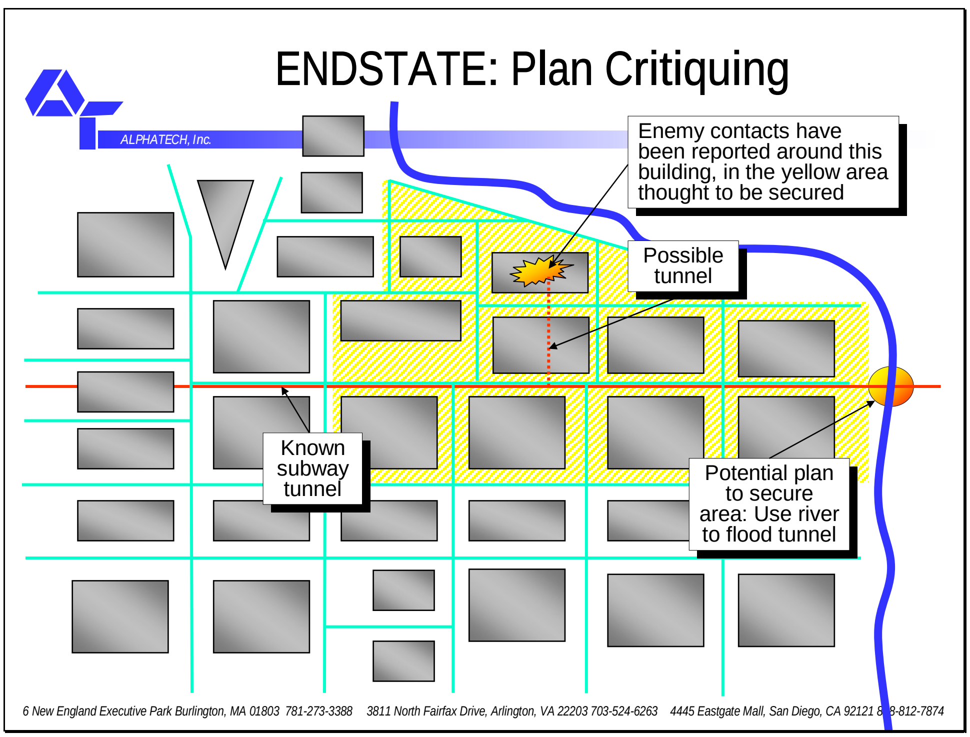

ENDSTATE: Goal-directed Reasoning
ALPHATECH, Inc.
Mob
Objective
A
To control power for the shaded section of the map, unit A should divert to this substation once their objective proves unattainable
orth Fairfax Drive, Arlington, VA 22203 703-524-6263 4445 Eastgate Mall, San Diego, CA 92121 858-812-7874


ENDSTATE: Mobility Reasoning
ALPHATECH, Inc.
Enemy
A
CSAR unit
6 New England Executive Park Burlington, MA 01803 781-273-3388 3811 North Fairfax Drive,
4445 Eastgate Mall, San Diego, CA 92121


ENDSTATE: Plan Critiquing
ALPHATECH, Inc.
Enemy contacts have been reported around this building, in the yellow area thought to be secured
Possible tunnel
Known subway tunnel
Potential plan to secure area: Use river to flood tunnel
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Evaluation via Simulation

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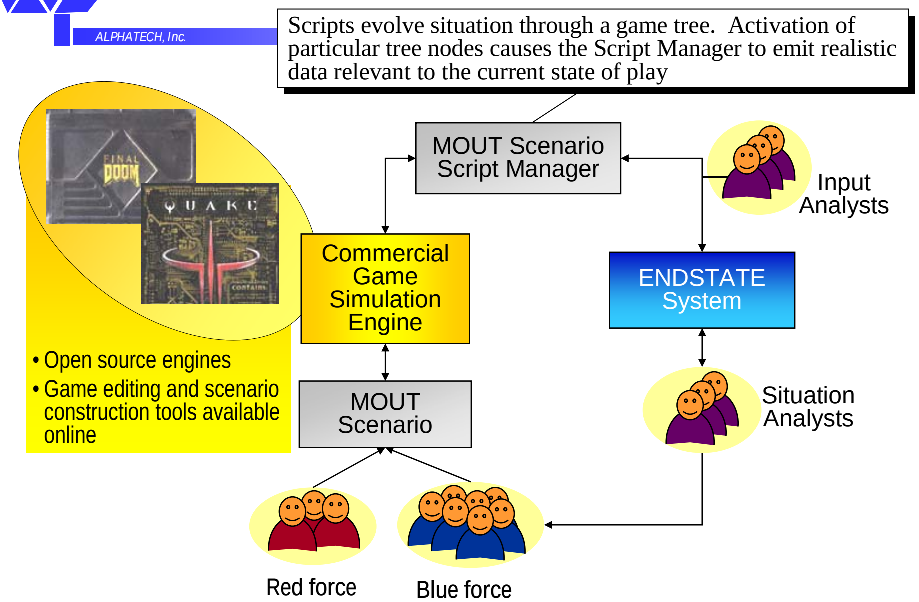

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Maneuver CoA Analysis Summary

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- Evolving CONOPS for urban tactics create challenges for effective tactical C2
  - Control of combined arms and netted fires at smaller echelons
  - Use of unmanned vehicles for recon and force projection
- Challenging research efforts are required in
  - Scalable contingency planning in complex urban environments
  - Large-scale, detailed knowledge representation of urban landscape
  - Hands-free, heads-up displays for plan authoring and critiquing
- Payoff will be systems that
  - Provide tactical suggestions for the use of small combined arms teams as change occurs
  - Alert ground commanders to implications of tactical decisions

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Urban Effects-Based Target Development

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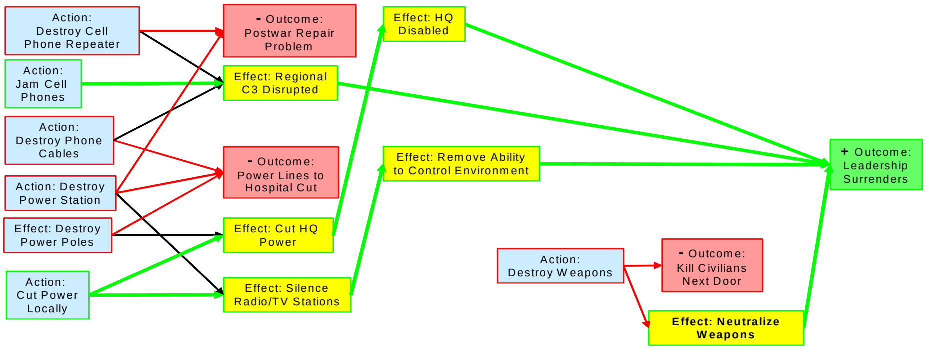

- Develop ground-based, small-unit courses of action
  - Use models of environment, infrastructure, and adversary
  - Predict and assess which lethal and non-lethal actions produce desired effects

What is Effects-Based Urban Network Targeting?

ALPHATECH, Inc.

- Effects-based operations (EBO) concept...
  - Select operational tasks that achieve desired effects and reduce/eliminate undesired effects
  - Account for effects by understanding mechanisms
  - Use full range of elements of national power
    - DIME (diplomatic, information, military, economic)
- ...applied to urban warfare.
  - Model city plus inhabitants as complex adaptive system of systems to find centers of gravity (COGs)
    - PMESI^2 (political, military, economic, social, infrastructure, information)
  - Exploit IPB/ISR to populate/update COG target set analysis (TSA) models
  - Develop targets, fires and maneuver effects, and ROEs for the urban fight

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Emerging Effects-Based Urban Doctrine

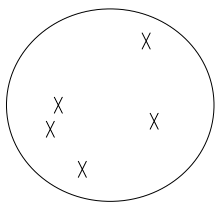
ALPHATECH, Inc.

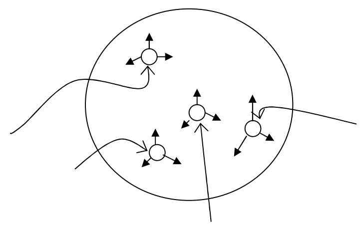
EBUNT plans Maneuver Warfare effects in addition to Precision Fires effects

Concept of Critical Nodal Assault

Deep Strike
some nodes can be *destroyed* by indirect precision fires

Close Combat
some nodes can be *seized* by small unit precision maneuver





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Why apply EBO to urban operations?

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- Achieve economy of force
- Avoid attrition warfare or siege
- Preserve legitimacy and reduce noncombatant casualties
- Support full spectrum operations, including MOOTW

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Problem: Urban-specific challenges for EBO

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Urban terrain exacerbates imperfect information

- Greater emphasis on human factors COGs (political, economic, and social) relative to terrain and buildings
- Greater density of potentially undesirable effects
  - Collateral damage, negative media impact, tightly coupled COGs

Urban terrain fragments command and control

- Requires rapid decision making at tactical level with operational significance
  - Chasing bad guys through neighborhood X may endanger operational goal of cordial relations with native ethnic group
- Targets are dispersed, hidden, mobile, or politically sensitive

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Emerging Technologies for EBUNT

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Technical Challenges	Promising New Technologies
Enhanced Operational Net Assessment	Rapid Knowledge Formation for building COG models
Increased importance of human factors in urban COG Analysis	Belief networks to support wargaming, esp. leadership and sociopolitical models
Increased infrastructure density and detail, tighter coupling of COG networks	Hybrid optimization and inference techniques for high-fidelity target set analysis

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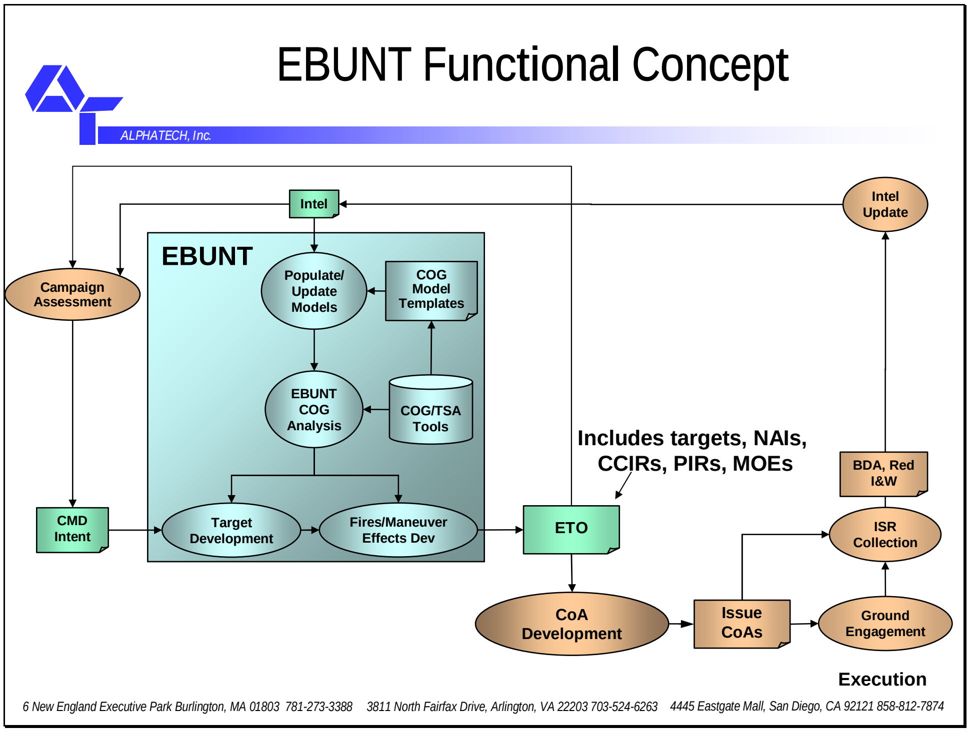
EBUNT Functional Concept
ALPHATECH, Inc.
Intel
Intel Update
EBUNT
Campaign Assessment
Populate/ Update Models
COG Model Templates
EBUNT COG Analysis
COG/TSA Tools
Includes targets, NAIs, CCIRs, PIRs, MOEs
BDA, Red I&W
CMD Intent
Target Development
Fires/Maneuver Effects Dev
ETO
ISR Collection
CoA Development
Issue CoAs
Ground Engagement
Execution
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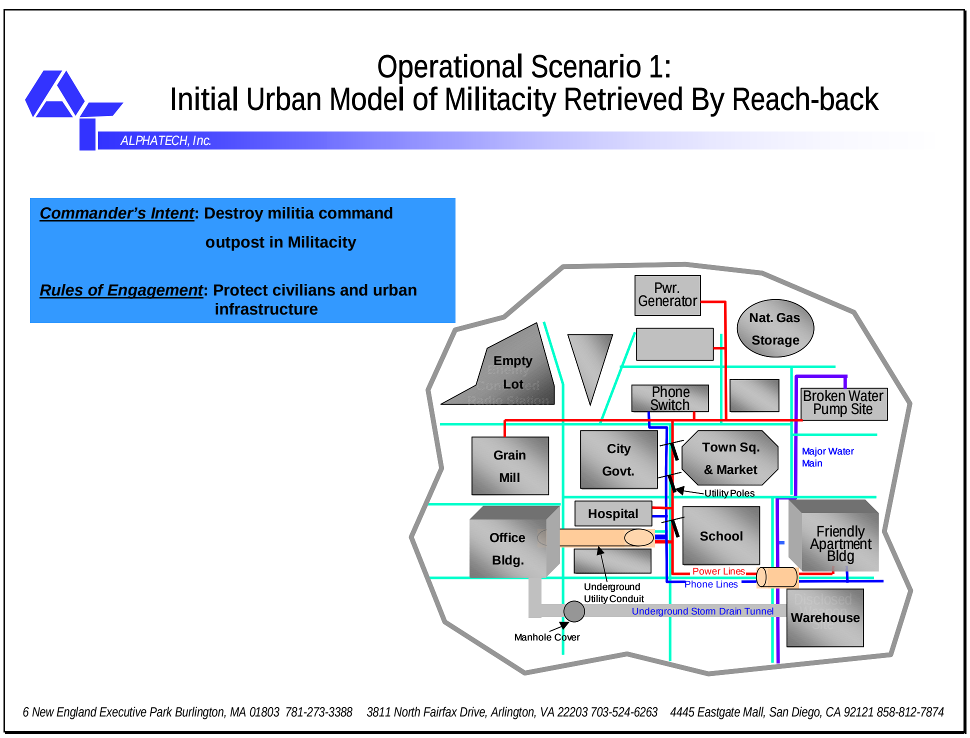
Operational Scenario 1:
Initial Urban Model of Militacity Retrieved By Reach-back
ALPHATECH, Inc.
Commander's Intent: Destroy militia command outpost in Militacity
Rules of Engagement: Protect civilians and urban infrastructure
Pwr. Generator
Nat. Gas Storage
Empty Lot
Phone Switch
Broken Water Pump Site
Major Water Main
Grain Mill
City Govt.
Town Sq. & Market
Utility Poles
Hospital
Office Bldg.
School
Friendly Apartment Bldg
Power Lines
Phone Lines
Underground Utility Conduit
Underground Storm Drain Tunnel
Manhole Cover
Warehouse
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Operational Scenario 2:
Intel Officer Fills Model With Current ISR

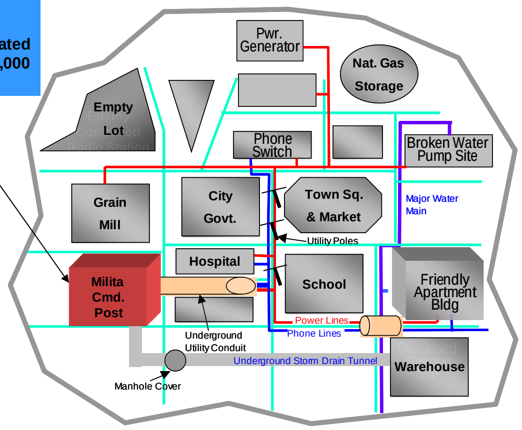
ALPHATECH, Inc.

***Commander's Intent*: Destroy militia command outpost in Militacity**

***Rules of Engagement*: Protect civilians and urban infrastructure**

***Combined Operations Intel Center*: Outpost located in bottom left sector of city of 10,000**
No other known red targets

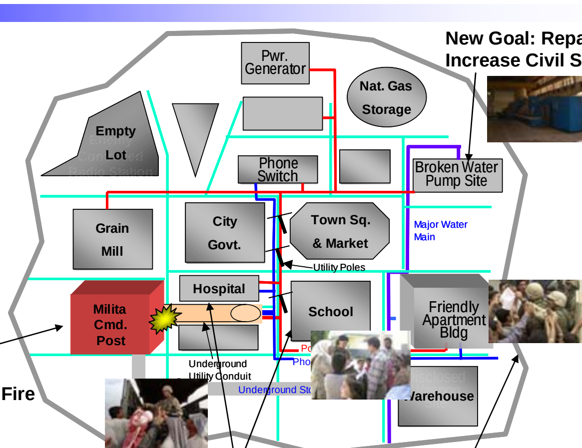
Intel Officer Fills Model With Current ISR



Operational Scenario 3:
Initial EBUNT Development

ALPHATECH, Inc.

New Goal: Repair
Increase Civil Support



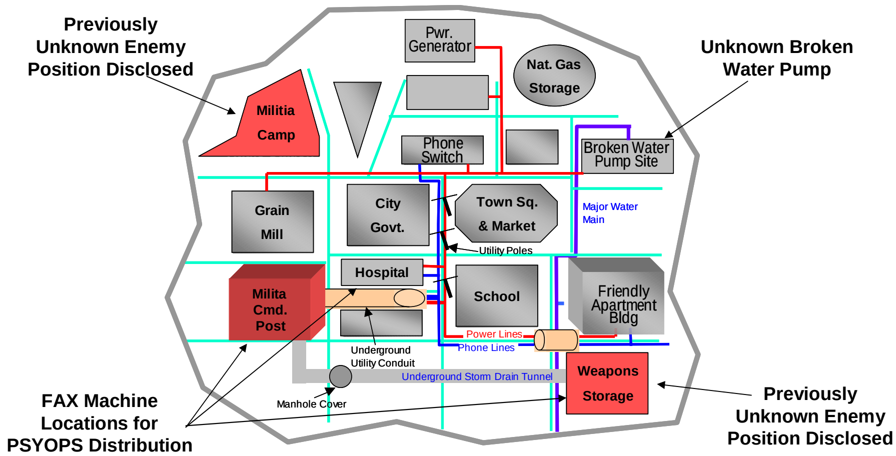
Revised:
- **Dismount Attack vs. Precision Fire**
- **Tactically Local Attack on EP & LOC utility connections**
- **Update ISR**

New Goals:
- **Provide Protection**
- **Increase Civil Support**

New Goals:
- **Distribute PSYOPS Leaflets**
- **Collect New Intel**

Operational Scenario 4: New Intel From Civilians Entered Into Model

ALPHATECH, Inc.



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Operational Scenario 5: Update EBUNT

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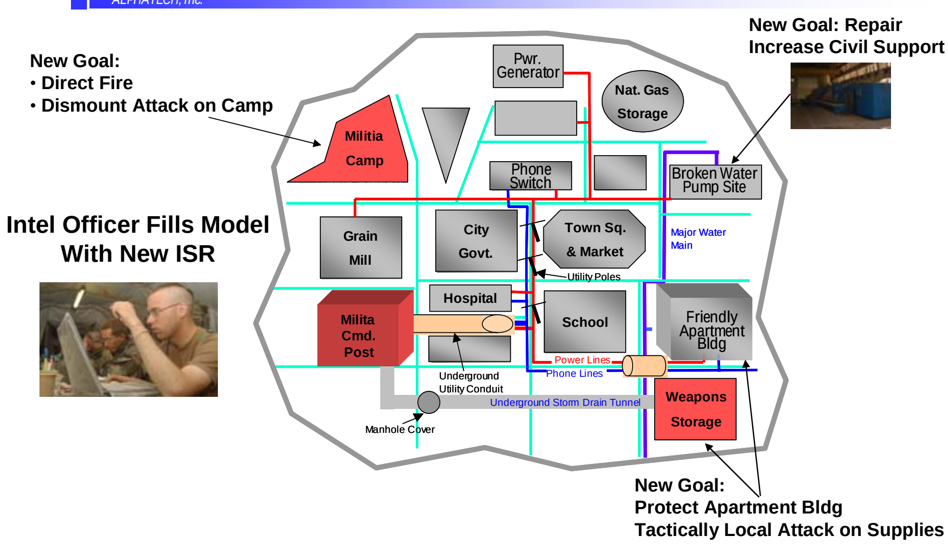

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Example EBUNT Program Component: Enhancing Operational Net Assessment

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- Intel officers must rapidly populate COG models
  - 72-96 hour deployment lead time for some urban ops
  - Need consistent interpretation of infrastructure data from world-wide repositories
- DAML+OIL ontology markup language provides semantics
- Key ontology elements
  - Represent EP + POL infrastructure
  - Represent supported activities and interdependencies
- Leverage MIDB schema
  - Many ontology elements used in COG analysis already captured

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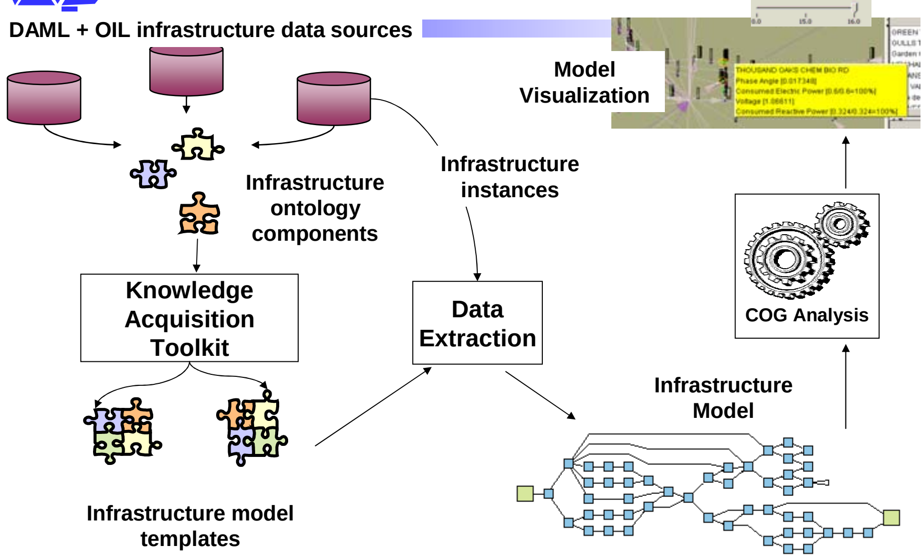
EBUNT ONA Technology Concept



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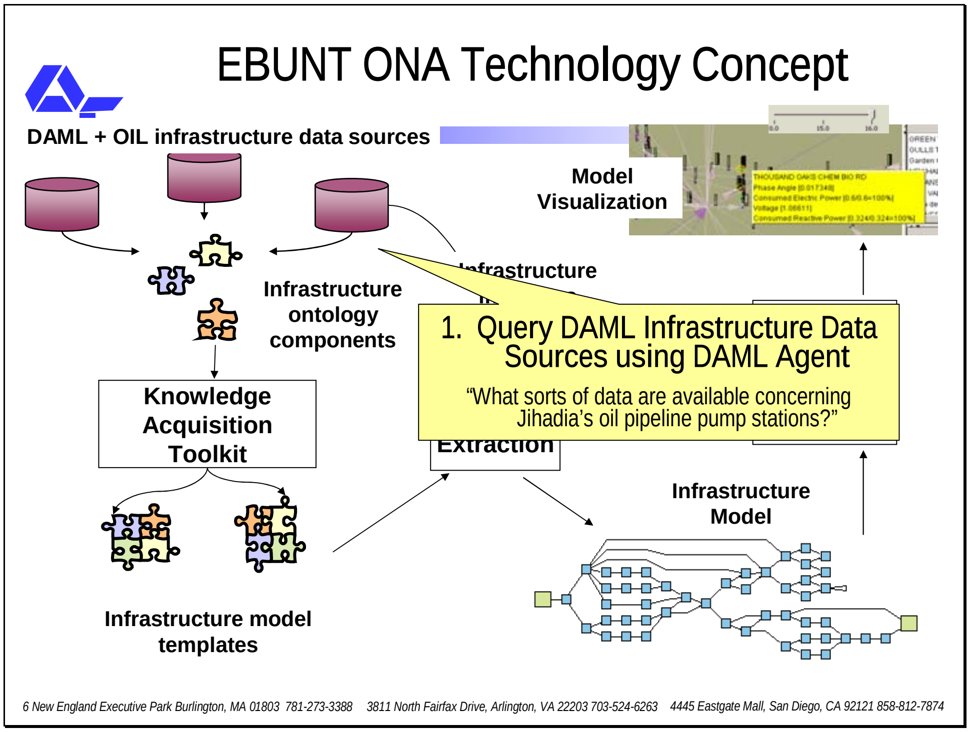
EBUNT ONA Technology Concept
DAML + OIL infrastructure data sources
Model Visualization
Infrastructure ontology components
Knowledge Acquisition Toolkit
Extraction
Infrastructure Model
Infrastructure model templates
1. Query DAML Infrastructure Data Sources using DAML Agent
"What sorts of data are available concerning Jihadia's oil pipeline pump stations?"
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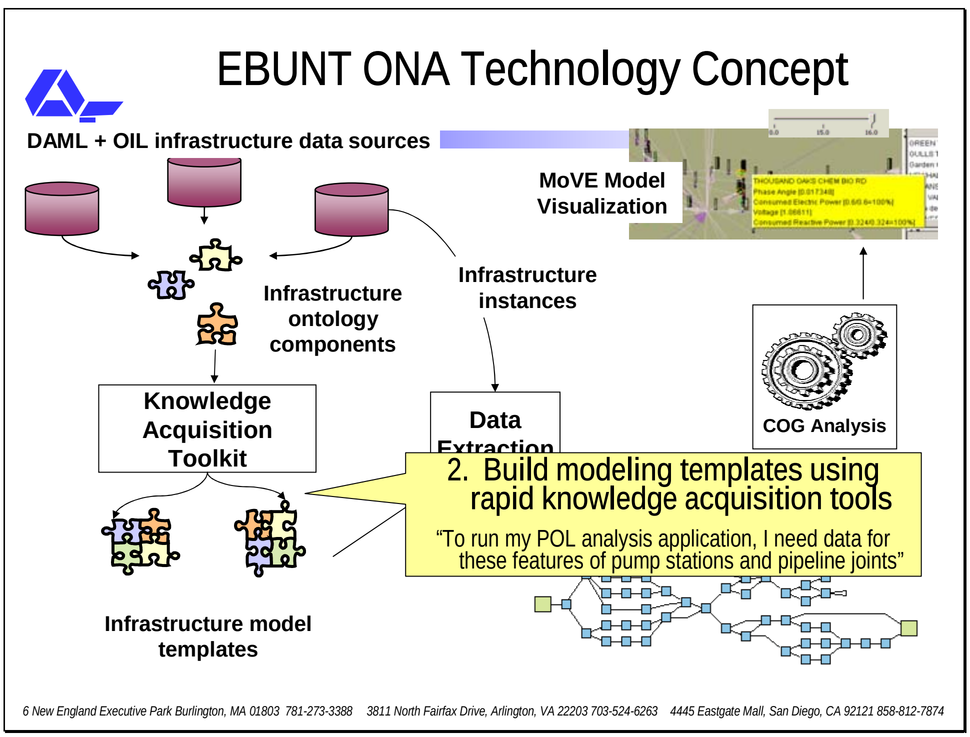
EBUNT ONA Technology Concept
DAML + OIL infrastructure data sources
MoVE Model Visualization
Infrastructure ontology components
Infrastructure instances
COG Analysis
Knowledge Acquisition Toolkit
Data Extraction
Infrastructure model templates
2. Build modeling templates using rapid knowledge acquisition tools
"To run my POL analysis application, I need data for these features of pump stations and pipeline joints"
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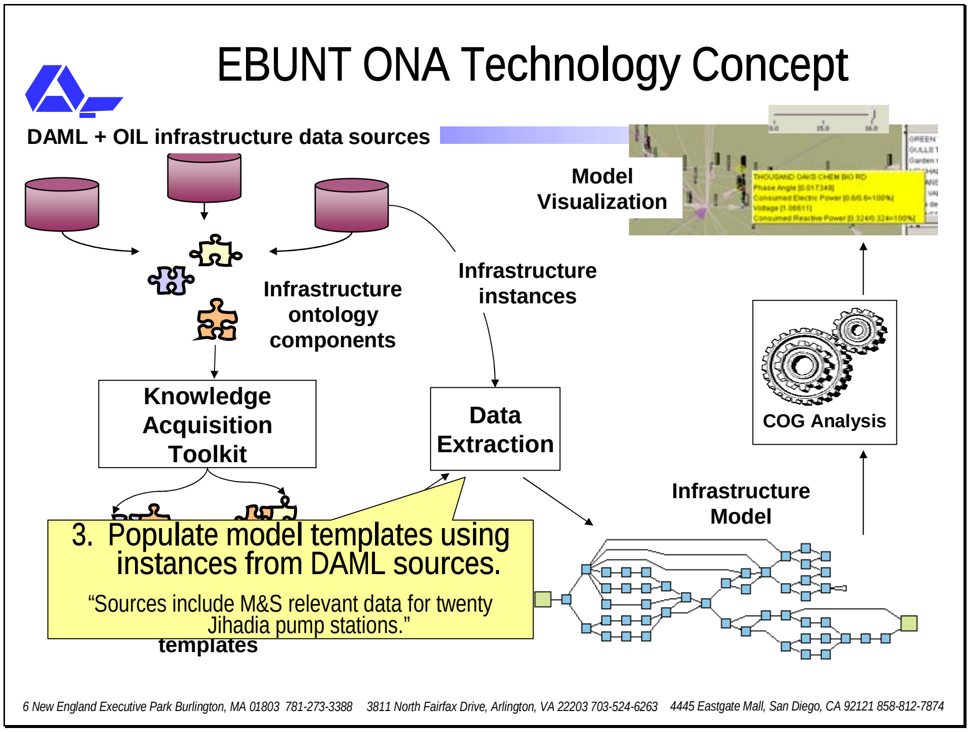
EBUNT ONA Technology Concept
DAML + OIL infrastructure data sources
Model Visualization
Infrastructure ontology components
Infrastructure instances
Knowledge Acquisition Toolkit
Data Extraction
COG Analysis
Infrastructure Model
3. Populate model templates using instances from DAML sources.
"Sources include M&S relevant data for twenty Jihadia pump stations."
templates
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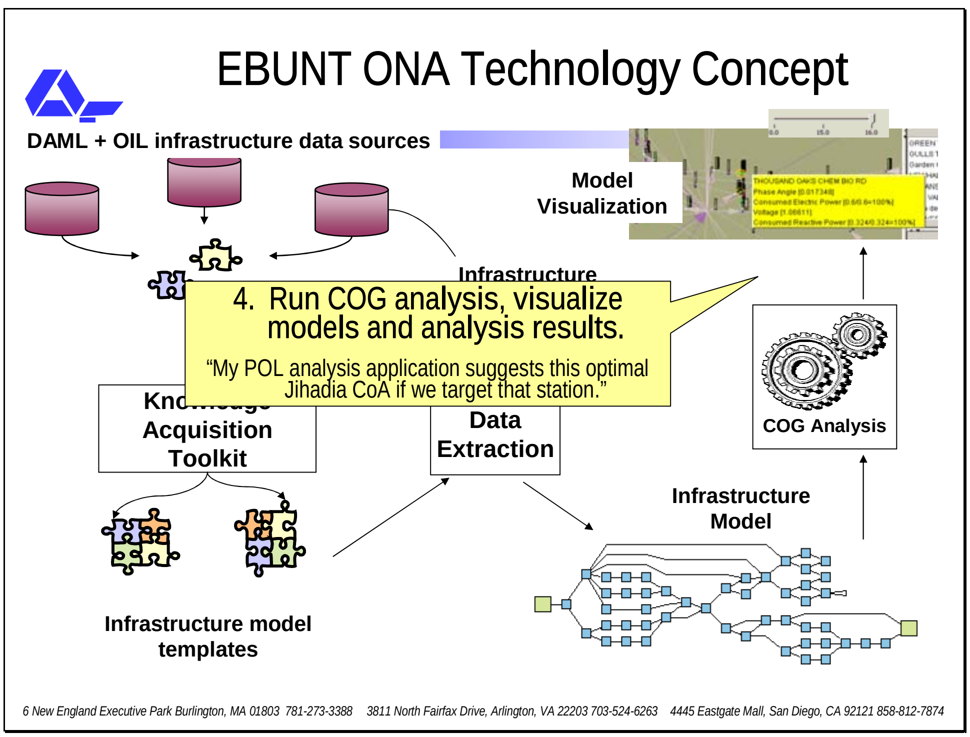
EBUNT ONA Technology Concept
DAML + OIL infrastructure data sources
Model Visualization
Infrastructure
4. Run COG analysis, visualize models and analysis results.
"My POL analysis application suggests this optimal Jihadia CoA if we target that station."
Acquisition Toolkit
Data Extraction
COG Analysis
Infrastructure Model
Infrastructure model templates
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Urban Network Targeting Summary

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- EBUNT is a challenging extension of effects-based planning to the urban environment
  - Intel collection and exploitation
  - Sociopolitical modeling
  - Detailed, complex, tightly-coupled urban COGs
- EBUNT provides target development, fires/maneuver effects assessment and planning
  - Analogous to target development and weaponeering in air ops cycle

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EBUNT technology development opportunities?

ALPHATECH, Inc.

- Are services interested in a technology solution to this problem?
  - Army/Marine commanders are trained to select objectives/targets that achieve desired effects
    - Skepticism about performing this task better with automation
  - Command structure for Army/Marines is necessarily decentralized
    - Different model than Air Force central planning/decentralized execution
  - Real need is for more complete intelligence picture and analysis
    - More HUMINT and better IPB on the urban environment

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APPENDIX E: DARPA ENDSTATE FOGLIGHT FINAL SUMMARY BRIEFING

Fog Light

Dynamic Interfaces for the Warfighter

"The great uncertainty of all data in war is a peculiar difficulty, because all action must, to a certain extent, be planned in a mere twilight, which in addition not unfrequently — like the effect of a fog or moonshine — gives to things exaggerated dimensions and unnatural appearance."

Clausewitz

30 November, 2004

Battlefield Stress Makes Interfaces Ineffective

- The platoon soldier is an 18 year old recruit from Arkansas
  - Not seasoned
  - Not a lot of education
  - Basic training only
- Command direction must be clear and crisp in all circumstances
  - The "fog of war" impedes decision making in the middle of battle
  - Force fragmentation in urban combat forces decision making down the chain of command
- Current and next generation C2 systems fail to improve prosecution while moving the next 10 feet
  - No time to interpret a fire hose of information
  - Lack skill interpreting complex map symbology
  - Mental stress impacts reasoning from maps to real scene

What are We Trying to Do?

The warfighter needs computer interfaces that adapt to the context and the individual

- Vision
  - Decision support tools that customize themselves to the user based on understanding of information displayed, individual, and situation
  - Effective user interfaces for dynamically composed command direction
- Approach
  - Combine diagrammatic reasoning techniques and intelligent interface methods drawing on psychophysical understanding of human sensing systems
  - Develop context-aware systems that can transmit information in a best-first order
- Benefits
  - More accurate decisions under duress
  - Improved utilization of next generation C2 systems (e.g., HURT, RAID)
  - Reduced development time for more effective interfaces

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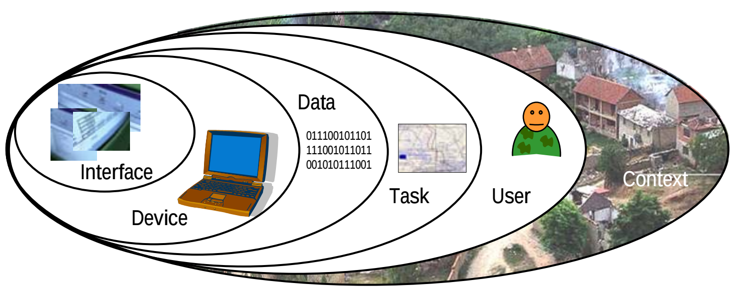
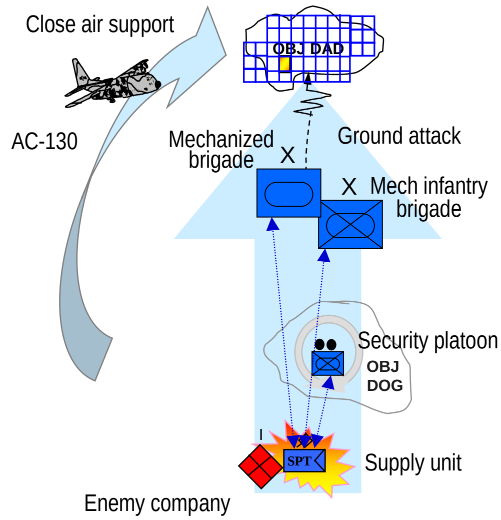
Context-Aware Information Systems



- Conventional interfaces are minimally aware of device
  - Screen size, color depth
- Context-aware systems must
  - Take into account user context
    - User preferences and cognitive style
    - Interactions with other users
    - Current task and situation
  - Determine interface parameters that
    - Encode critical elements of the current problem and its solution
    - Generate effective interfaces on the fly

Example: Reacting to a Flanking Attack

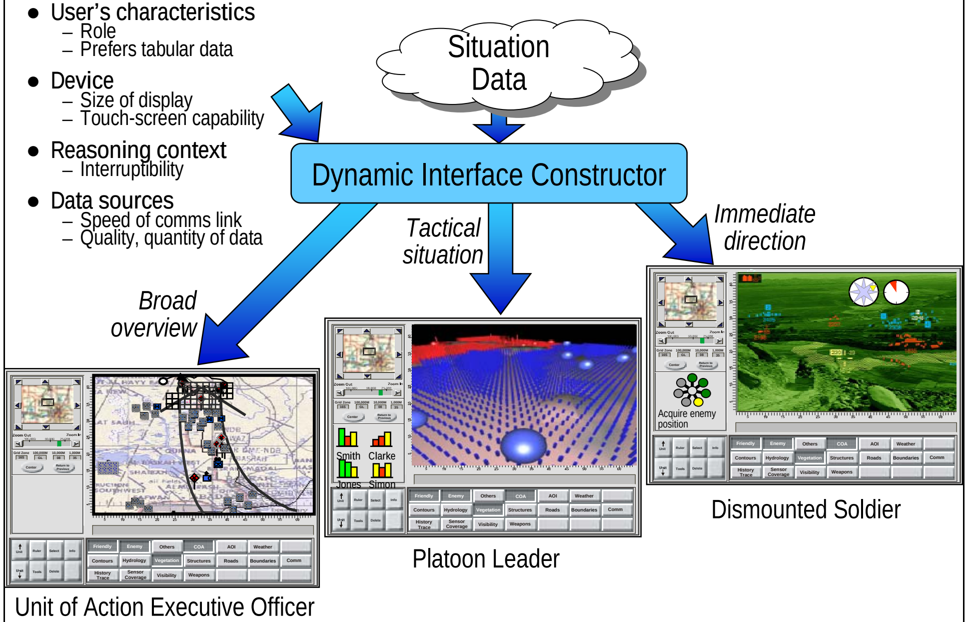


Useful Display Transformations

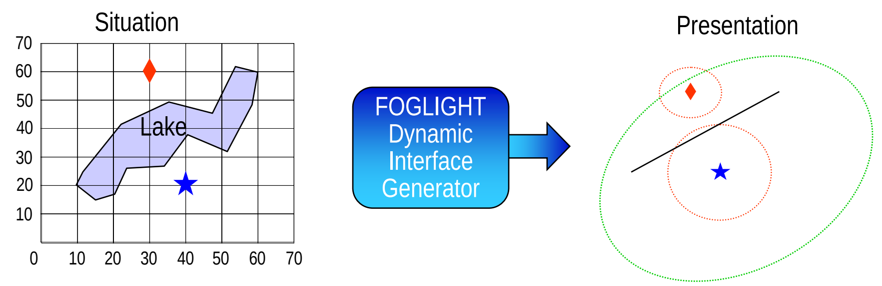
1. Derive decision space from user role
2. Highlight salient graphical elements (e.g., assets, control measures)
3. Gray out irrelevant elements of display
4. Highlight implications of decisions
5. Transform distances into directly comparable graphical elements (e.g., pie charts showing time to target)
6. Transform other relevant dimensions (e.g., unit strength) into common graphical elements (e.g., color of time-to-target slice).

Role-Specific Interfaces

- User's characteristics
  - Role
  - Prefers tabular data
- Device
  - Size of display
  - Touch-screen capability
- Reasoning context
  - Interruptibility
- Data sources
  - Speed of comms link
  - Quality, quantity of data



Computing What Data to Display



Friendly forces at <40,20>
1 tank company, 40% fuel level, range 60 miles
Weapons range 2 miles

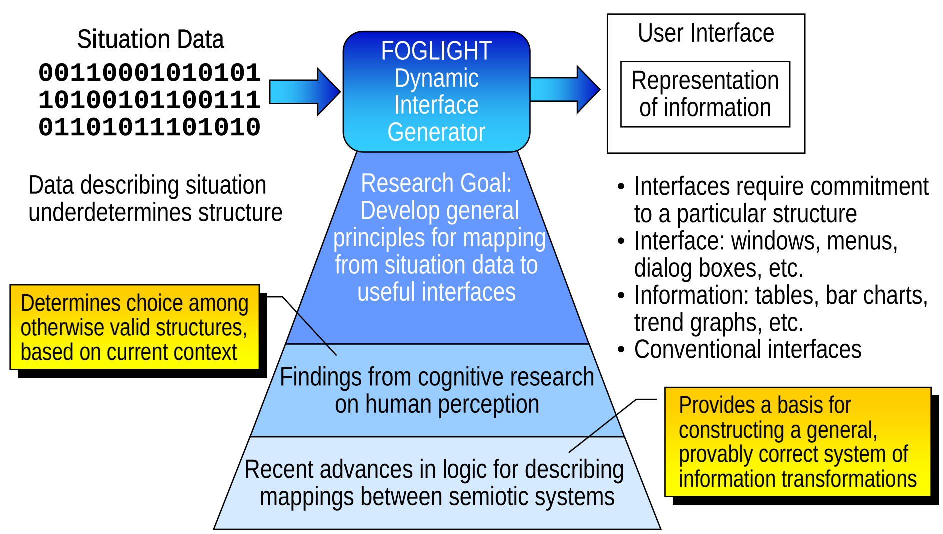
Enemy forces at <30,60>
1 tank company
Weapons range 1.5 miles

Lake at {<10,20>,<21,41>,<35,50>,<48,45>,<54,61>,
<60,60>,<58,49>,<52,32>,<40,37>,<35,27>,
<23,27>,<20,17>,<15,15>}

Air temperature 40°F

Display directly represents key inferences
- Lake is a mobility barrier
- Lake is not a barrier to fires
- Units are not in range for engagement
- Blue force can reach red force with current fuel reserves
- Display of engagement range would change if temperature were below freezing, enabling one or both forces to traverse lake
- If lake were a mountain, fires boundary would not cross line

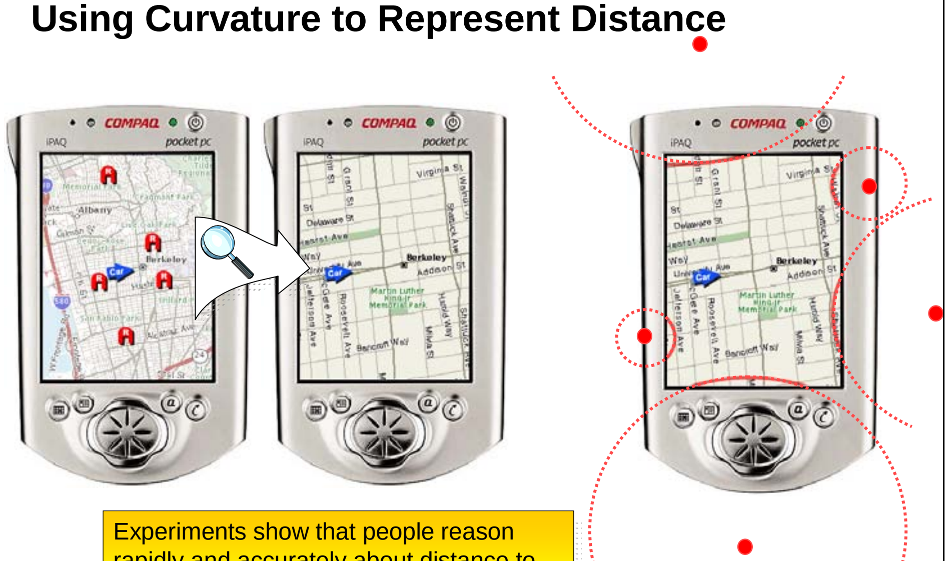
Challenge: Determine Principles for Mapping Situation Data to Interfaces



Pre-Attentive Visual Features

Feature	Researchers
Line (blob) orientation	Julész & Bergen (1983); Wolfe(1992)
Length	Triesman & Gormican (1988)
Width	Julész (1985)
Size	Triesman & Gelade (1980)
Curvature	Triesman & Gormican (1988)
Number	Julész (1985)
Terminators	Julész & Bergen (1983)
Intersection	Julész & Bergen (1983)
Closure	Enns (1986); Triesman & Souther (1985)
Color (hue)	Triesman & Gormican (1988); Nagy & Sanchez (1990)
Intensity	Triesman & Gormican (1988); Beck et al. (1983); Julész (1971)
Flicker	Julész (1971)
Direction of motion	Nakayama & Silverman (1986); Driver & McLeod (1992)
Stereoscopic depth	Nakayama & Silverman (1986)
3D depth cues	Enns (1990)
Lighting direction	Enns (1990)

Using Curvature to Represent Distance



Experiments show that people reason rapidly and accurately about distance to places off-screen via the curvature of arcs

Source: HALO Project. Patrick Baudisch, Microsoft Research, & Ruth Rosenholtz, PARC, Inc. April 10th, CHI 2003. www.patrickbaudisch.com

Display for UA XO

- **User**
  - Skilled at map interpretation
  - Capable of fast accurate recall
  - High training level
- **Role**
  - FCS XO
  - Decision maker
  - Task: create counter-attack plan without compromising mission objective, time and resource constrained
- **Device**
  - FCS command vehicle
  - Workstation with good comms
- **KB**
  - COP including enemy and friendly locations, with missing data
- **Reasoning Mode**
  - Orient/Decide

Use conventional symbology on a map-based interface

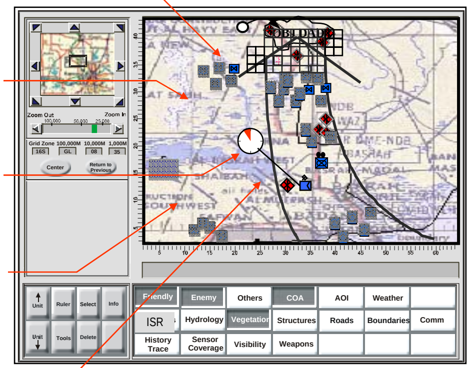
Sacrifice low-level details in order to show big-picture context

Graphically show critical deadlines for individual units

Make use of graphical features that require high resolution

Refresh when new data enters COP

Keep display relatively fixed, graying out irrelevant aspects, while preserving context to support recall



Display for Platoon Leader

- **User**
  - Skilled motor control
  - Weakly learned symbology
  - Low training level
- **Role**
  - Platoon leader
  - Coordinate recon effort under deadline
- **Device**
  - Portable workstation
  - Remote sensors
- **KB**
  - COP including enemy and friendly locations, with missing data
- **Reasoning Mode**
  - Orient/decide

Employ a 3D, overview perspective display, avoid symbolically rich map-based displays

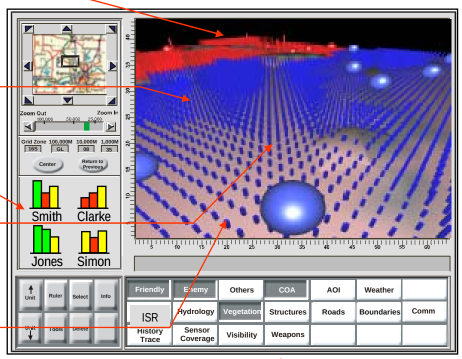
Provide an overview of immediate area of action

Make member status evident in the display

Display all platoon members, and any known enemies, in the context of trafficability constraints

Adjust update rate to ensure accurate picture

Minimize display reconfiguration



Display for Platoon Soldier

- User
  - Skilled motor control
  - Weakly learned symbology
  - Low training level
- Role
  - Platoon soldier
  - Recon task: time constrained, identify type & number of enemy
- Device
  - Heads-up display
  - Remote sensors
- KB
  - COP including enemy and friendly locations, with missing data
- Reasoning Mode
  - Observe/orient

Employ a 3D, first person perspective display, avoid symbolically rich, map-based display

Provide a localized, highly detailed point of view

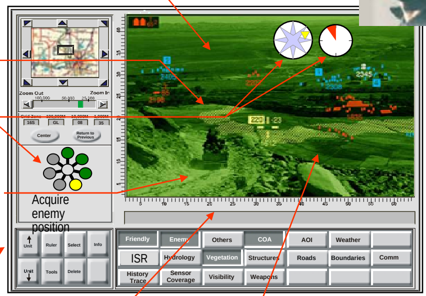
Reify task progress, deadlines, direction

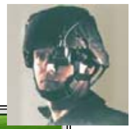
Display all known adversaries and any known cover and trafficability constraints

Minimize input requirements

Adjust update rate to ensure accurate picture

Allow display to reconfigure to bring new threats into focus





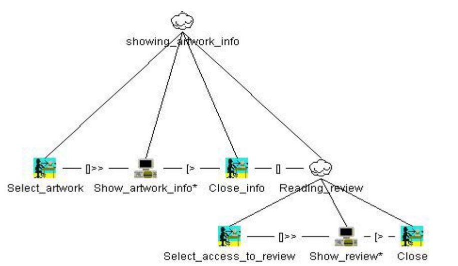
How is it Done Today?

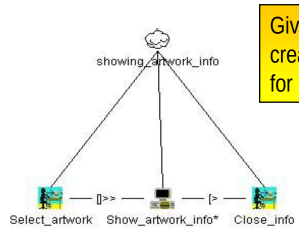
- Minimal commitment, maximum generality
  - Microsoft Word displays any text, Microsoft Excel displays tabular data
  - No commitment to semantics of information
  - Major engineering effort to make interface useful
  - No consideration given to user’s environment or task context
- Mission-specific interfaces
  - Developed for particular tasks (e.g., Command Post of the Future)
  - Single-purpose, designed with respect to semantics of information
  - Minimal consideration given to user’s environment or task context
- Accommodating user variance causes unmanageable requirements
- Cognitive task analysis can create user models, but is labor intensive
- Recent work on generating interfaces from parametric descriptions focuses on alternative displays
  - Web phones

Generating Interfaces from Parameters

- Leverage research on context-aware UI design: mapping interface parameters to a UI based on *rules.*
- Generally a three-step process:
  - Framework for *designing rules* (how do we map IP to UI?)
    - No general solution; design of rules is problem dependent
    - Project goal: framework for rule design and experimental methodology for instantiation
  - Framework for *encoding rules* (how are rules stored and implemented?)
    - E.g., TERESA (Mori, Paterno, Santoro)
  - Framework for *runtime support* (how do rules generate multiple UIs at runtime?)
    - E.g., Dygimes (Clerckx, Lyuten, Coninx)

Example for Encoding Rules: TERESA





Given task model, create framework for multiple UIs

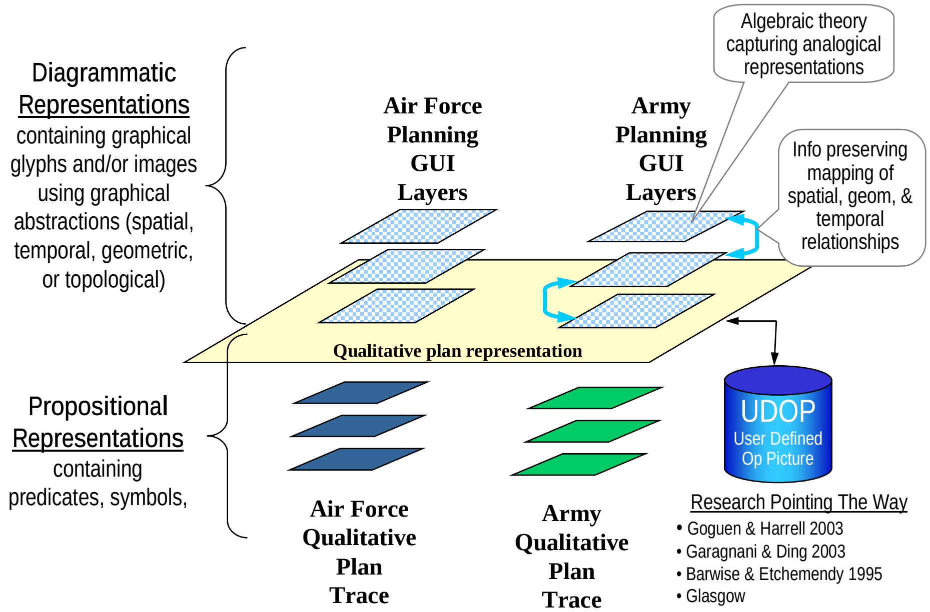
What's New, and why will it Work?

- Enabling the principled composition of user interface elements to construct interfaces that preserve key structural properties of the input data
  - Informed by cognitive perceptual theory
  - Grounded in a sound logical basis that provides the means for verifying soundness and proving properties of the system
- Combining the advantages of current paper-based planning tools, such as maps and sketches, with automated inference processes that dynamically generate interface displays
  - Configuring displays on the fly based on user's context
- Achieving a 10x improvement in performance
  - Reduce training time (direct encoding and task-based user interface generation will lower learning curves)
  - Reduce time on task (compressing inference steps and reducing user interactions with the system because the interface displays elements of the structure of the solution)

Who Cares? What Difference will it Make?

- Enable Army FCS to achieve its Warfighter Machine Interface (WMI) objective
  - Enable machine interfaces to adapt to human capabilities
- Improve communications in joint operations
- Reduce need for staff specially trained in single-purpose displays
  - Develop principles of interface synthesis that transcend particular applications
- Improve situation awareness and decision quality in dynamic replanning
  - Configure interfaces to support human decision making under stressful conditions
- Enable faster task completion with less training
  - Get inside the enemy's decision loop

Diagrammatic Reasoning For Joint Operations



What are the Risks and the Payoffs?

- Risks
  - Scientific foundation not yet sufficiently established
  - Computers not yet fast enough
- Payoffs
  - Shorten development timelines by raising the level at which GUIs are specified
  - Lower the barriers to adoption of automated C2 systems
  - Reduce training costs and staff requirements for new systems
  - Interfaces that improve human cognitive capabilities across all applications

How Much will it Cost, over what Timeframe?

- 4 years
- $40 million

What are the Midterm and Final Checks for Success?

- Best test is evaluation under realistic circumstances
- Midterm evaluation in simulated environment
  - Focus on breadth of evaluation
- Final evaluation in mixed simulation/real wargame environment
  - Focus on depth of evaluation
- Extensive experimentation framework an integral part of program
  - Conjoint designs for rapid evaluation of multiple alternatives
  - Fractional factorial designs for in-depth evaluation of performance

Two-Phased Experimentation Framework

- Prototype phase
  - Multiple prototype interfaces presented to various users (contexts)
  - Users express preferences via ranking
  - Conjoint analysis determines test setup and provides optimal mapping and analysis
  - Advantage: inexpensive, off-line, no performance assessment required
  - Disadvantage: mapping based on user preferences, not performance
- Testing phase
  - Optimal interface and variants presented to various users (contexts)
  - Assess user performance in an exercise
  - Fractional factorial design determines test setup and provides optimal mapping and analysis
  - Advantage: assessment based on performance; can correlate preferences to performance (determine limits on preferential adjustability)
  - Disadvantage: more labor-intensive (battlefield scenario required); requires realistic performance metrics (real-valued AUTL metrics, etc.)

Conjoint and Fractional Factorial Design and Analysis of Experiments

- *Problem:* Determine the “optimal” configuration of an object, where the configuration is a combination of various features.
  - Example: new car design
  - Features: color, horsepower, style, gas mileage, etc.
  - Goal: optimize features to maximize sales to a given demographic
- *Issue:* Can’t test all possibilities (combinatorial explosion)
- *Solution:* Carefully select combinations to test so that statistical inferences can be made for any combination.
- *Question:* What is “optimal”?
  - Combinations which are *preferred*
    - Conjoint analysis
  - Combinations which *perform*
    - Fractional factorial design and analysis

Conjoint Design and Analysis

- Determine optimal configuration by eliciting user *preferences*
- *Experiment:* Present carefully chosen collection of configurations to users and solicit rankings of those configurations (preferences)
- *Benefits:* Determine the effect of various features on preference
  - Main effect, secondary effects, etc.
    - Which features are most critical, least critical, and so on…
  - Strength of effects
    - Quantify the effect of a feature setting on user rating or preference
  - Quantify confounding
    - Interaction of various features

Fractional Factorial Design and Analysis

- Determine optimal configuration by assessing user performance
- Experiment: Present carefully chosen collection of configurations to users and assess (real valued) performance of those configurations (e.g., under simulated battle conditions)
- Benefits: Determine the effect of various features on performance
  - Main effect, secondary effects, etc.
    - Which features are most critical, least critical, and so on…
  - Strength of effects
    - Quantify the effect of a feature setting on performance
  - Quantify confounding
    - Interaction of various features

Why Now?

- Rapid increase in capabilities and complexity of current and anticipated C2 systems will place interface design on the critical path
  - Humans are likely to remain in the loop
  - Interface design is a major element of new systems design
- Recent research has generated promising results
  - Cognitive science results in the study of human perceptual biases
  - Emergence of alternatives to propositional representations of problem spaces
  - Advances in the theory of algebraic mappings between semiotic systems

References

- Diagrammatic Reasoning
  - Barwise & Etchemendy 1995
    - Developed theory of heterogeneous reasoning, incorporating propositional and diagrammatic elements
  - Goguen & Harrell 2003
    - Used algebraic abstract data type theory to define semiotic morphisms providing information preserving transformations between representations
    - Applied theory of info visualization to measure quality of several concrete examples, identifies general principles
  - Garagnani & Ding 2003
    - Developed hybrid (analogical/propositional) representational framework for planning avoiding classic limitations
    - Observed 2 to 90 times speed up solving classic planning problems such as Blocks World and Eight-Square
  - Glasgow & Malton 2003
    - Applied array theory to capture spatial relations as symbolic arrays
    - Observed computational benefit from the implicit representation of spatial and topological constraints

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  - Clerckx, Lyuten, Coninx
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APPENDIX F: REFERENCES

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